THE JOURNAL OF THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES

FEBRUARY 1961

Vol. 55, No. 1 Whole No. 448

THE JOURNAL OF THE
ROYAL ASTRONOMICAL SOCIETY
OF CANADA

Vol. 55, No. 1 FEBRUARY, 1961 Whole No. 448

SIR WILLIAM HERSCHEL AND HIS PLACE IN THE HISTORY OF SCIENCE*

By Walter Balderston

University of Western Ontario, London, Ontario

Two hundred years ago in November 1757, two young German musicians landed in England to escape from the turmoils of war in their native Hanover, and to try their fortunes. They were William Herschel, age 19, and his older brother Jacob. So began the career of a man who may be called the father of modern astronomy and is justly entitled to his place among his brilliant contemporaries, Priestley, Dalton, Buffon, and Hutton, the men who laid the foundations of the sciences of chemistry, biology, and geology.

Although William Herschel prospered in his new home, he showed little evidence of scientific genius. William, and his six brothers and sisters, had received from their father Isaac Herschel not only the musical talent that marked the entire family but also a sound education. In addition to the training provided in the garrison school of the Hanoverian Guards, in whose band Isaac Herschel was employed, William and his brothers were given special tutoring in languages. Their instructor was a man of wide intellectual interests and inspired in his pupils a love of mathematics and philosophy which was furthered by their father who encouraged his sons by demonstrations and discussions within the family circle. The young Herschels had a liberal education in spite of the meagreness of their father's income.

In England William found employment as a free-lance musician and after his brother returned to Hanover, filled his hours of lonely leisure with continued reading, especially on philosophical subjects. The young man gradually established his reputation in Yorkshire to which he had

*The substance of this paper was delivered to the London Centre, R.A.S.C.

moved from London and was finally appointed organist of the parish church at Halifax. Soon afterwards, in 1767, he accepted an invitation to become the musical director for a new chapel just built in Bath, then a resort at the height of its reputation.

The move to Bath proved to be the turning point in his career. He was soon able to bring a younger brother, Alexander, and sister Caroline, to assist him. Alexander remained a musician at Bath the rest of his life, giving William invaluable help in later years in the design and construction of telescopes. Caroline, however, joined William when his interests turned to astronomy in a partnership that endured the rest of her brother's life. It is always difficult to assess the importance of personal elements in the success of a great man, but it seems clear to us, as it did to their contemporaries, that Caroline was essential to her brother's success. Acting as his clerk and assistant, her contribution was, as her nephew said, "her extra-ordinary powers of application in long continued effort with the extreme accuracy in all that she did". It is pleasant to report that her life was not all drudgery, however willing. Her brother made her a telescope and set her to scan for new comets. She discovered seven altogether and her contributions were fully recognized and appreciated by William's scientific friends.

William Herschel's musical career, busy as it seems, was not demanding enough. His interest in mathematics and philosophy led him to astronomy and before long he was learning to make his own mirrors and to construct his own telescopes. Soon, thanks to the manual dexterity which he credited to his "fiddling", he was constructing instruments of excellent quality and learning how to use them. The manufacture of telescopes and mirrors remained an important activity for the rest of his active life for he supplemented his income by the sale of these instruments to wealthy amateurs.

His telescopes were reflectors, using mirrors of speculum metal, an alloy of tin and copper. His first instruments were Newtonian in which the parabolic mirror reflects the image back to the mouth of the tube where it is diverted to the side by a flat mirror set diagonally. The observer must stand on a ladder or platform at the elevated end. We must remember that Herschel spent nearly every night when observation was possible on his exposed perch unprotected from the wind and weather. In his later instruments Herschel used a modified form, named after him, in which he could dispense with the secondary mirror by tilting the main mirror and directing the image directly to his magnifying eyepiece at the side of the tube. The elimination of the second mirror produced a brighter image, and the reduction in accuracy was not important for Herschel's purposes.

The telescope with which Herschel made most of his observations was twenty feet long with a mirror eighteen inches in diameter. But his desire to penetrate still further into the secrets of the heavens led him to construct a monster, forty feet long and carrying a mirror four feet across. King George III contributed 4000 pounds for this instrument as well as an annual sum for its operation but the instrument never fulfilled the hopes of its maker. It proved to be too cumbersome to operate and its mirror too difficult to keep polished. The elaborate scaffolding and huge tube gave the telescope the appearance of a field gun and made it a well-known local land mark. After William's death the dismounted tube remained in the Herschel garden until it was crushed by a falling tree, and even yet it may be seen on the Herschel coat of arms.

Once Herschel had constructed a suitable instrument, he began a systematic survey of the heavens, listing and describing every object of interest that came within his view. This programme of systematic observation continued to be his basic procedure for the rest of his life. His observing soon attracted the attention of others, especially Dr. William Watson whose father was physician to George III. Both father and son were members of the Royal Society. Dr. Watson became one of Herschel's closest friends and most helpful supporters. Through him Herschel became a member of a local literary society to which he contributed many papers dealing with a number of scientific subjects. Bath was an excellent place for an amateur scientist as many prominent persons came to visit the popular resort where Herschel made their acquaintance.

At the time Herschel began his observations, the interest of astronomers was virtually limited to the solar system although there had been speculation concerning the fixed stars. Kant, the German philosopher, had suggested that the solar system might have originated in the condensation of a nebula and he offered the suggestion that some of the nebulous objects visible in the telescope might be distant star systems. But this acute speculation had no observations to support it. It was Herschel who provided evidence on which a theory of the structure of the heavens might rest.

Herschel started his first survey in 1775 and began a second four years later with an improved instrument that permitted him to observe stars of the eighth magnitude. This second survey brought him world fame.

On March 13, 1781, Herschel noticed a hitherto unrecognized "nebulous star or comet", which he quickly saw had a visible disk. Soon he was able to measure its motion. The news of discovery was sent to others and it was soon realized that Herschel had, in fact, discovered a new planet, the first planet in the solar system to be discovered in historic times.

Herschel's reputation was made. The Royal Society awarded him the Copley medal and in November 1781, elected him a member. Herschel proposed the name "Georgium Sidus" for his discovery in honour of George III and his own name was also proposed but before long Uranus became the accepted name.

Herschel always retained a parent's love for his celestial child, later discovering two satellites for it as well. But the excitement over the new planet was a distraction from his principal interests. He later in life explained that the discovery had not been a happy accident. He was systematically studying the heavens and on March 13, 1781, came its turn to be observed. "I had gradually perused the great Volume of the Author of Nature and now came to the page that contained a seventh planet."

As the discovery of Uranus marks the abandonment of Herschel's musical career, it is convenient to trace the remainder of his life before considering his scientific achievements and their significance. Herschel had now gained the attention of Sir Joseph Banks, who had begun his reign of more than forty years as president of the Royal Society. Through his influence and that of others George III was persuaded to make Herschel his astronomer with an annual salary of 200 pounds a year. Later Caroline was given fifty pounds a year for her services. The appointment involved few duties but required moving to Windsor to be near the royal court. William and Caroline moved from Bath and, after trying a couple of other locations, settled down at Slough where Herschel's house and some of his instruments are still to be seen.

In 1785 William Herschel married Mary Pitt, a widow. The marriage was to all appearances a very happy one and although it was an emotional shock to Caroline to share her brother's affections there was no interruption to their scientific partnership. In 1792 William's son John was born and Caroline was soon giving the nephew the same adoring affection she bestowed on his father. Herschel's life from then on was uneventful. He took regular holiday trips with his family through England and Scotland and during the brief peace of Amiens visited Paris in 1802 to meet scientific colleagues from whom he had been separated by the French wars. In 1814 he was made a knight of the Royal Guelphic Order by the Prince Regent.

John Herschel had a brilliant record as a student at Cambridge and after a start at studying law, returned there for an academic career in mathematics. But William and Caroline were no longer able to continue their labours alone and John soon gave up his own ambitions to return to Slough in 1816 to work with his father. William's health, although not his

intellectual interest, gradually failed and he died on August 15, 1822. Caroline, after her brother's death, returned to the Hanover she had left half a century earlier to spend what she thought to be the few remaining years of her life with her youngest brother. She lived another 26 years. Her rather lonely life was comforted by the continued friendship of the royal family and the affectionate company of a niece. She followed with great interest the career of her nephew John who was able to visit her occasionally. Her contributions were recognized by a gold medal from the Royal Society and election to the Royal Irish Academy and the Royal Astronomical Society. She retained an alert mind and body until her death on January 9, 1848 in her ninety-eighth year.

Although William's most original contributions to science were in sidereal astronomy, he by no means neglected the solar system. In addition to measuring the height of lunar mountains, Herschel made close studies of several of the planets. He recognized the polar caps of Mars and suggested they might be frost deposited in a moderate atmosphere. He determined the length of a day on the same planet to within two minutes of the presently accepted value. His studies of sun-spots convinced him that they represented depressions in the glowing surface of the sun and he suggested that they might be breaks in fiery clouds that revealed the cool, dark surface of the sun below. His most original enterprise was an attempt to discover if sun-spots had an effect on the climate of the earth by trying to discover if there was a correlation between the number of sun-spots and the price of wheat in England. He concluded that many sun-spots and low prices, that is good weather, went together.

Herschel seems to have made the assumption that it was likely that all celestial bodies were in motion, and he attempted to discover the direction and magnitude of the motion of the sun relative to the near stars. The attempt had been made earlier but with inconclusive results. The method employed was analogous to observing from a moving vehicle where objects in front seem to move away from the line of motion and objects behind to move in toward the line of motion. Herschel's determination of the solar apex, using the motions of 13 selected stars was within ten degrees of the presently accepted location, and he estimated the velocity of the sun as about that of the earth in its orbit, a considerable overestimate. A later repetition of the calculations based on a greater number of stars was less successful, so Herschel may have enjoyed a certain amount of luck in his first effort.

Herschel's surveys of the heavens had been inspired by a long-standing problem, the determination of the annual parallax of the stars. It had been recognized since Copernicus that if the earth moved about the sun,

a small change in the position of the stars should be observable. The great distance of the fixed stars had defeated all attempts to measure so small an effect, but Galileo had suggested that it might be possible if a near and a distant star could be found so nearly in the same line of sight that they appear to be a double star. Herschel made his sky surveys in order to find suitable pairs of such stars. Herschel also failed to determine the parallax but his results were perhaps even more significant. It soon appeared that there were many more double stars than there should be if such pairs were merely the accidental association of a distant with a near star. After twenty years of study Herschel offered evidence to show that some pairs were in periodic motion around each other. For the first time there was a reasonable basis for assuming that the law of gravitation held for distant stars as well as the solar system.

Herschel's surveys led him to consider the distribution of stars and what he called "the structure of the universe". His method was to count the number of stars visible in the field of his telescope. After making some two thousand such counts, or "gages" as he called them, Herschel concluded that the stars visible in his telescope formed an isolated system, roughly resembling a disk in shape. He recognized that he had no conclusive proof of this as he could not be sure that his instrument could reveal all the stars in the Milky Way system. The Milky Way itself appears as it does because we are looking through the length of the disk. He suggested that the disk is some six thousand light-years in length (using modern units) and about one thousand light-years in depth with the sun near the centre. Although this is only a fraction of the dimensions presently assumed for our galaxy, they are much greater than any distances that had been suggested for the fixed stars at that time.

Herschel's telescope revealed many objects of a diffuse and extended appearance which could not be resolved into stars. He soon began submitting catalogues of such objects to the Royal Society and eventually catalogued several thousand such objects, completely supplanting the hundred and five nebulae catalogued by Messier. Herschel was not content merely to catalogue and he soon was classifying his nebulae and suggesting a pattern of development by which they came into being.

> I need not repeat that by my analysis it appears that the heavens consist of regions where suns are gathered into separate systems and that the catalogues I have given comprehend a list of such systems; but may we not hope that our knowledge will not stop short at the bare enumeration of phenomena capable of giving us so much instruction? Why should we be less inquisitive than the natural philosophers? . . . Let us then compare together some of the numerous sidereal groups, so that we may trace the operations of natural causes so far as we can perceive their agency.

Herschel's comparison of his sidereal groups led him to postulate an evolutionary development by which stars, originally evenly distributed in

space, concentrated as a result of gravitational attraction into groups around the larger stars. In time these aggregations become more and more compact finally becoming globular clusters. The numerous "Planetary nebulae" (which presented observable disks like planets) were the intermediate stages in this process. If the gravitational attraction is balanced by "projectile forces" the result will be a stable system that will persist indefinitely. Just as Herschel's description of the structure of the heavens assumed enormous distances, his evolutionary theory required an equally extended period of time for its operation.

At the time he developed this theory Herschel assumed that all nebulae are composed of stars even though he could not resolve them in his telescope. When he realized that some nebulae could not be composed of stars but consist of diffuse luminous matter he revised his theory and turned it around. Instead of taking stars as the beginning of his process, he assumed that they represented the end product. His new theory proposed that the diffuse, extended, luminous material contracted to form stars with the planetary nebulae the intermediate stage. He apparently never completely abandoned, however, the belief that some of the nebulae might be distant star systems.

This account is not intended to give an exhaustive description but to present the evidence from which the significance of William Herschel's career in the history of science can be determined.

It is clear that Herschel deserves his contemporary reputation as one of the ablest astronomers of his time, indeed of any time. He built telescopes of a quality and power unequalled in his lifetime and observed with an acuity that few have surpassed. It may be said that he forced himself and his instruments to perform to the limit of their ability. In addition he prepared and promptly published systematic and accurate observations which provided the basis for modern astronomical research. In this Tycho Brahe alone is his rival.

Finally, he broke through the barrier of the heavens—*coelorum perrupit claustra* is the Latin his son placed on his tomb. Herschel's studies of the structure of the heavens have proved to be remarkably fruitful. They marked out the major fields of astronomical research until our own time.

Astronomers, especially amateur astronomers for whom he could appropriately be a patron saint since he began as an amateur, may justly hold William Herschel to be the founder of the modern period of their science.

But Sir William's place in history is more important and significant than even this suggests. His thinking was informed with two principles of extraordinary fruitfulness. First, he assumed that the universe, as far as

it was revealed by his instruments, operates by natural causes, and until it could be shown otherwise these causes must be assumed to be those we find operating on earth.

His second principle was the assumption that the universe is a dynamic one, continually changing and developing. In adopting these views Herschel was not an isolated voice. He was applying in astronomy the principles that contemporaries were applying in geology and biology. James Hutton, the Scottish geologist who is even less appreciated by the ordinary man than Herschel, set out a similar uniformitarian theory of geological change over ages of endless time. It is surely significant that Herschel knew Hutton and read his books. Erasmus Darwin, Buffon, and Cuvier were not so explicitly but in much the same fashion, applying the same principles to biology. It is not fanciful, therefore, to recognize Herschel as one of Darwin's intellectual ancestors.

Herschel then is one of the major prophets of our modern world view. All things, the works of man, the teeming organic life of our planet, and the stars in their courses display the same character. All is in constant change. Everything has been absorbed in historicity.

All creation is ever-changing, ever-new.

PROFESSOR F. J. M. STRATTON, F.R.S.

By R. O. Redman

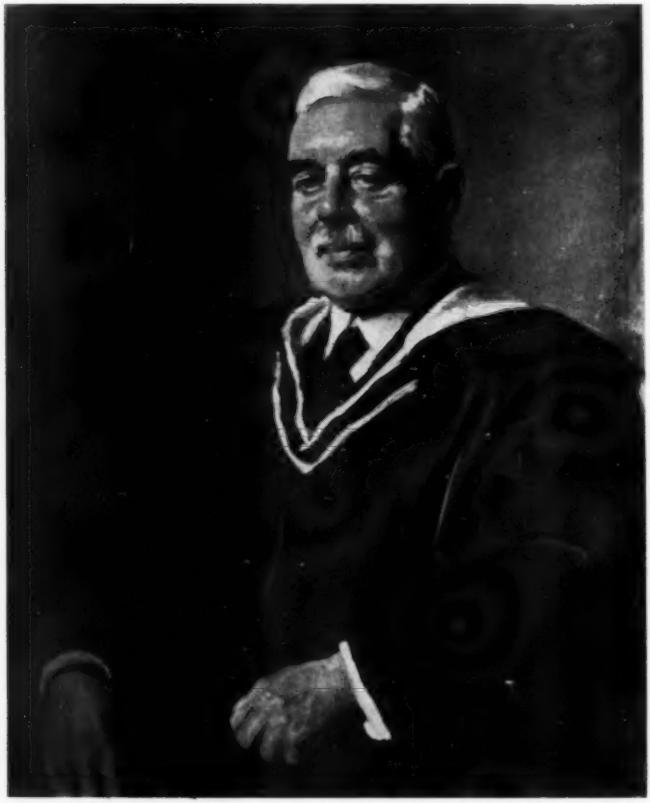
University of Cambridge, Cambridge, England

A long life of active service to astronomy, to international science, and to humanity in general, recently came to an end with the death on September 2, 1960 of Professor F. J. M. Stratton.

Frederick John Marrian Stratton was born in Birmingham, England, on October 16, 1881. After a distinguished scholastic career he took his B.A. degree in 1904 from Gonville and Caius College, Cambridge. His first astronomical paper appeared in 1906 and dealt with the effect of tidal friction on the obliquities of members of the solar system, work for which he was awarded a Smith's Prize at Cambridge. He became a mathematical lecturer at Caius College and, a few years later, Assistant Director of the Solar Physics Observatory, Cambridge, under H. F. Newall. His well-known interest in novae appears to have first been aroused by the appearance of Nova Lacertae in 1910 and Nova Geminorum 2 in 1912. But the outbreak of war in 1914 temporarily put an end to his astronomy; he hurried back from the Crimea (where he had been preparing to observe the total solar eclipse of August 21), joined the Army immediately, and served with great distinction in France, being awarded the D.S.O. and the Légion d'Honneur.

In 1919 he returned to Cambridge, resigning his post at the Solar Physics Observatory to become Senior Tutor at Caius College, and earned the respect and affection of many pupils during the difficult years of the early 1920's. He continued to give lectures on astronomy and astrophysics, some of which formed the basis of his book *Astronomical Physics*. In 1928 he relinquished his tutorship to succeed Newall as professor of astrophysics and director of the Solar Physics Observatory, a post he held for nearly 20 years.

Shortly before this appointment he and C. R. Davidson had successfully observed the chromospheric spectrum at the total solar eclipse of 1926 in Sumatra. At other eclipses he had consistently bad luck with the weather, when with Newall in 1927 in Norway, and with his own expeditions to Siam 1929, Canada (Magog) 1932 and Japan 1936. Only at the last of these was partial success possible, and even then thick cloud covered the sun almost exactly at second contact. Although a man of the strictest principles he would confess with a chuckle that he liked gambling, "and the best gamble I know is an eclipse".



F. J. M. STRATTON, after a painting by Sir Oswald Birley.
(By courtesy of Gonville and Caius College, Cambridge.)

With his other great enthusiasm, novae, he was more successful. When Nova Herculis appeared in 1934, the poor English climate and the inadequate equipment at the Solar Physics Observatory did not prevent him from getting a remarkably good record of the spectrum changes during subsequent months. A year or two later he supplemented his spectrograms with material sent from all over the world, to produce in collaboration with W. H. Manning the well-known *Atlas of the Spectrum of Nova Herculis*, perhaps the most complete record we have of a nova outburst. At about the same time also he completed and published work on Nova Persei, 1901.

At the start of the Second World War, in 1939, Stratton was eager to go on active service again, but much to his disappointment he was refused on account of age. However, he succeeded in being accepted by the Royal Corps of Signals for other duties, involving extensive travelling in Canada, Australia, India and elsewhere. At the end of the war, with all British universities and observatories still badly disorganized, and with his own retiring age close ahead, Stratton realized he would be unable to do much more active astronomy. However, before retiring in 1947, he arranged for the amalgamation of the Cambridge Observatory and the Solar Physics Observatory, until then independent, and also wrote an interesting history of both Observatories. After his retirement he served for two years as Deputy Scientific Adviser to the Army Council and continued to be very active on numerous committees.

His 70th birthday was celebrated by the publication, with A. Beer as editor, of *Vistas in Astronomy*, which ultimately grew much beyond the originally intended *Festschrift*. For some additional biographical details the reader may be referred to the introduction to *Vistas*, vol. 1.

He was a Fellow of the Royal Astronomical Society for 55 years and served for many years on its Council; he was President 1933–35 and Foreign Secretary 1945–55. He was an Honorary Member of the Royal Astronomical Society of Canada. He was awarded the O.B.E. in 1929 and was elected to the Royal Society in 1947.

Stratton was best known to many astronomers as a staunch supporter of the International Astronomical Union, of which he was General Secretary 1925–1935. He was one of the very few who had attended every I.A.U. General Assembly up to, and including, the Moscow meeting. In recent years he had served unobtrusively as President of Commission 38, helping the movement of astronomers wishing to work in foreign countries. Those whose memories go back to the Stockholm meeting in 1938 will recall his famous after-dinner speech when, rosy-faced and chuckling, he thanked our hosts in seven languages, to a crescendo of delighted applause.

But astronomy was only one of Stratton's activities. He was General Secretary of the British Association 1930–35, General Secretary of I.C.S.U. 1937–1952, President of the Cambridge Philosophical Society 1930–31, President of Caius College 1946–48. He was a life-long supporter of the Unitarian Church and very active on behalf of ex-servicemen's societies and causes.

He had a somewhat old-fashioned interest in psychical phenomena, although he would laughingly admit that he was not the kind of person to whom ghosts appeared. He was President of the Society for Psychical Research 1953–55.

Perhaps his most important contributions to science and learning were by way of help and encouragement to younger men, help which was not by any means restricted to astronomers or Englishmen. His exceptional good nature, generosity and modesty, always inclined him to put other men's interests above his own. A bachelor, he was a Fellow of Caius College for 54 years, and occupied the same set of rooms there for about half a century, rooms which saw a steady stream of visitors, Old Caians, astronomers, and others, who could always be sure of a cheerful hospitable welcome from "Chubby".

In his younger days Stratton was always in a hurry. He thought fast, decided fast and moved fast. His speech was to match, being so rapid that even his closest colleagues sometimes found difficulty in following him, and I still remember the amazement of a European astronomer and his wife, both good linguists, when hearing him spell the name of the present Astronomer Royal—W, double O, double L, E, Y—in what seemed to be well under one second.

Both speech and movements slowed down after a serious illness in 1931. However, for the most part he enjoyed good health up to an advanced age and not until his last year or two did he begin to use spectacles. As recently as last June he was taking an active interest in Nova Herculis, and he was dealing with the affairs of I.A.U. Commission 38 only five days before his death.

THE BRIGHT-LINE STARS OF CLASS B

By Dean B. McLaughlin

University of Michigan Observatory, Ann Arbor, Michigan

Introduction. Among the brighter stars of class B, about 10 per cent. are known to have bright lines of hydrogen. These are designated class Be. The first to be recognized were γ Cassiopeiae and β Lyrae whose emission lines were noted by Secchi in 1866. The greatest number of early discoveries resulted from the objective-prism survey of bright stars at the Harvard Observatory, published in *Harvard Annals*, vol. 56. Many additions were made among fainter stars during the classification of spectra for the *Henry Draper Catalog*. These photographic surveys were limited to the blue-violet region, in which Hβ is the strongest emission line. The low dispersion used for the fainter stars, as well as imperfect focus at the long-wave end of the photographic spectrum, resulted in failure of detection of many Be stars with only moderate or weak emission lines.

About 1919 a great increase of photographic sensitivity in the red became possible with the production of new sensitizing dyes. The red Hα line, the first of the Balmer series, is by far the strongest and the most advantageous for discovery, even on objective-prism spectra of low dispersion. At Mount Wilson Observatory in 1919, P. W. Merrill (1925) began a survey with a 10-inch camera and objective prism. Over a period of many years this resulted in the discovery of several hundred stars with Hα bright. The *Mount Wilson Catalog* together with its two supplements, contains 1088 entries. (Merrill and Burwell, 1933, 1943, 1949.)

The designation "Be" is sometimes used to include not only "normal Be" stars but such peculiar bright-line objects as Z Andromedae, BF Cygni, P Cygni, and XX Ophiuchi, or in fact any star with a bright-line spectrum that does not fall into the well-defined categories of Wolf-Rayet, planetary nebula, long-period variable, or other late-type absorption spectrum with added bright lines. The peculiar stars named are extremely interesting and pose many unsolved problems, but they lie outside the scope of our present discussion. We shall restrict our attention to the Be stars proper.

The Spectra. Except for the bright lines, the spectra of Be stars appear fairly normal. They may belong to any subdivision of class B, but they are more numerous in classes B3 and earlier. The numbers decline through B8 and B9, but there are a few early A stars in the *Mount Wilson Catalog*.

The absorption lines are fairly narrow in some stars, very diffuse in others. All intermediate degrees of widening occur. The higher lines of the Balmer series have wide hazy wings that denote Stark effect and indicate pressures in the reversing layers in the same range as those of non-emission main sequence B stars. The diffuseness of other lines (Mg II, Si III, He I, O II, etc.) is similar to that associated with rapid rotation in absorption-line B stars, and it is doubtless caused in that way. One abnormality that has been noted is probably connected with the presence of the bright lines. Most of the absorption lines appear somewhat weaker than we would expect from the amount of rotational widening, as if they were filled in by a continuum spread over the whole observed spectral range. This suggestion receives some support from the apparent strengthening of absorption lines in some stars whose emissions have temporarily disappeared. Examples of this effect were seen in γ Cassiopeiae and π Aquarii. The "veiling" effect seems especially pronounced in the "shell" stars.

The strongest bright lines are always those of hydrogen. A few stars have a great number of Balmer lines visible in emission. In 11 Camelopardalis, Burbidge and Burbidge (1953*a*) were able to resolve the bright lines to H 22. During one stage of its spectacular variations, γ Cassiopeiae showed the series strong out to H 30, and beyond there the blended lines merged with a strong continuum to shortward of the series limit. In different stars the emissions range from narrow to wide, and their widths are closely correlated with those of the stellar absorption lines. In most stars only a few of the lower Balmer lines are seen bright, and in many only Hα appears. There are no great intensity anomalies like those in the long-period variables of class Me. However, the Burbidges (1953*b*) found that several Be stars have the Balmer decrement much less steep than the simple theory predicts. Self-absorption in the lower lines of the series is suggested as a partial explanation.

Nearly all spectra with strong hydrogen emission have also bright lines of Fe II. These are often missed on low-dispersion plates or fail to show when low-contrast emulsions are used, but among the brighter Be stars contrast emulsions seldom fail to bring out numerous Fe II emissions if hydrogen is strong enough to show Hδ bright. Struve and Swings (1932) also found weak emission due to Ni II, Cr II, Mg II, Sc II, and Si II. It is rare to find He I emission in the photographic region. A few normal Be stars do have a bright line at λ5876 He I, the first of the diffuse triplet series. During its very active (and decidedly abnormal) phase, γ Cassiopeiae had very strong emission of He I and several other elements not usually conspicuous in Be spectra.

Line Profiles. Figure 1 shows schematically the kinds of profiles shown by the hydrogen lines in different Be stars. Beside them are shown corresponding profiles of helium lines formed in the stellar reversing layers. Each hydrogen profile consists of an underlying normal absorption line with broad Stark wings, upon which is superimposed centrally an emission line, or an emission-absorption structure, which may be wide or narrow. The emission profiles are fairly steep-sided, so that the lines have fairly definite outer edges on spectrograms of low dispersion.

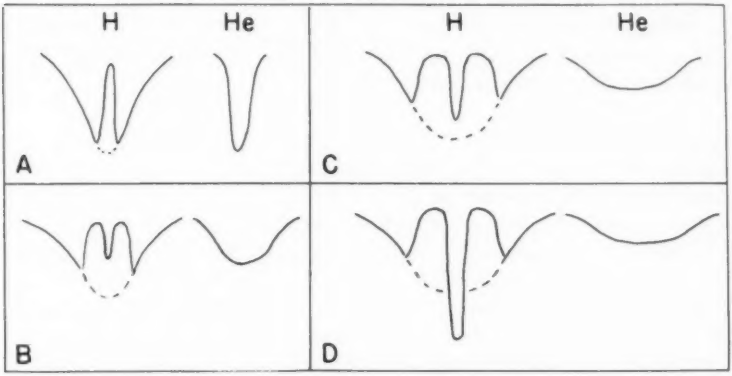


FIG. 1—Typical profiles of hydrogen and helium lines in spectra of class Be.

Among the brighter stars none have emission lines as nearly monochromatic as those of a diffuse gaseous nebula. The usual range of width is from 2 to 8 A. The narrowest lines appear single (figure 1 *A*) even with fairly high dispersion; 11 Camelopardalis is a good example. When the lines are more than 3 A. wide, a central minimum usually appears in the profile (figure 1 *B*). This is called the "central absorption". It is too narrow to admit of interpretation as a central core of the underlying broad absorption simply added to the profile of a uniform emission. Rather it is believed to be mainly a self-reversal, an absorption line formed in an outer layer of atmosphere and superimposed on the emission. A part of the dip, however, may be simply a minimum resulting in some way from the geometry and the motion of the emitting region.

In spectra with wider emission lines, the central absorption averages more conspicuous (figure 1 *C*) but there are exceptions. Some stars with wide double emission have extremely weak and vague central absorption. Among the stars with wide emissions, and *only* in this group, a considerable percentage have very deep central absorption (figure 1 *D*). Here

there is no doubt that it is a self-reversal. These lines are appreciably widened but flat-bottomed and without wings, like the profiles attributed to turbulent broadening in such supergiants as ϵ Aurigae. These are called "shell stars". The characteristics of their spectra will be discussed later.

In the stable Be stars, and at certain phases of the variable ones, the central absorption is truly central and the two emission components are of equal strength. We have already excluded P Cygni stars from consideration; in these objects the absorption is at or near the shortward edge of the emission, and if any emission appears to shortward of the absorption it is relatively weak. The behaviour of variable Be line profiles will be discussed in a later section.

Origin of the Emission Lines. The bright lines in all probability are produced by the Zanstra mechanism. Hydrogen atoms are ionized from the ground state by absorption of quanta on the short wave-length side of the head of the Lyman series at 912 A. Recombinations at higher energy levels will nearly all lead to emission of Balmer quanta in the process of cascading to the ground state. The work of Mohler (1933) showed that this process is adequate to account for the intensity of the Balmer emissions in normal Be stars. The main requisite is an atmosphere extensive enough to convert a large portion of the radiation shortward of 912 A. into Balmer quanta.

We can go farther and infer that a sufficiently extensive envelope will deplete the far ultraviolet radiation in an inner H II region and will have an outer region in which hydrogen is almost wholly neutral. Here the central absorption lines can be formed.

The Rotational Model. Struve (1931) first pointed out the correlation between widths of the absorption and emission lines. This is displayed schematically in figure 1. After allowance for instrumental broadening, all hydrogen bright lines in any one star have widths proportional to their wave-lengths. This suggests Doppler broadening, and it is the main foundation of the rotational model proposed by Struve. The wide winged absorption originates in the stellar reversing layer and its core is broadened by rotation. The outer wings are due to Stark effect. The measured profiles of lines of He I and Mg II support the rotational origin of widths of lines other than those of hydrogen. Slettebak (1949) found that the rotational velocities of some Be stars exceeded those of any absorption-line B stars in the large group studied by him. The rotational velocity of ϕ Persei was measured as 560 km./sec.

The emission lines are attributed to a rotating ring or thick disk of gas far out from the photosphere and lying in the equatorial plane. When we find narrow dark and bright lines we have a pole-on view of an object that is not fundamentally different from a star that has greatly broadened absorption and emission lines. The latter is viewed nearly in its equatorial plane. The frequency of emission lines of different widths is very nearly what we should expect if the poles of such systems were distributed in random orientations.

If we assume that the ring is supported entirely by its rotational velocity, we can compute its radius for any assumed stellar mass. The observed width of the emission is simply double the circular orbital velocity. For a "two-body system" consisting of the star and an atom in the ring, we have the well-known relation

$$M = a^3/P^2,$$

where M is the mass, a the radius of the ring, and P the period of rotation. The units are the solar mass, the astronomical unit, and the year. The velocity of the ring is

$$V = 2\pi a/P,$$

and by substitution we obtain

$$a = 4\pi^2 M/V^2.$$

If we use the velocity in km./sec., but keep a in astronomical units, this becomes

$$a = 890\ M/V^2.$$

A fairly typical main sequence B star would have $M = 5\ \odot$, and radius $R = 5\ \odot$. A typical rotational velocity for the emitting ring is 250 km./sec. From these values we obtain $a = 0.07$ A.U., which is approximately 3.5 R. The emitting region must be fairly extensive compared with the star.

The above is of course a crudely oversimplified picture, but it gives us an idea of the relative dimensions involved. If the ring (rotating at the adopted velocity) is closer to the star, it must be partly supported by gas or radiation pressure. Parts of it may be considerably more distant, since they would produce narrower emission structures superimposed on the wider and would tend to fill in the central minimum in the profile that results from a rotating thin ring. There cannot be a large amount of emitting gas closer to the star, for this would produce a wider bright line. There is probably some; this may be in part the origin of a wider and more diffuse emission that is clearly seen only at Hα.

Figure 2 is a cross-section of the rather oblate rapidly-rotating star and its extensive flatly lenticular envelope. The directions of view corresponding to profiles *A* to *D* in figure 1 are shown. Also shown is the division of the envelope into an inner H II region and an outer annular H I region. The radiation beyond the Lyman series head is depleted in the H II region and does not penetrate to the outer edges of the disk where gas may be streaming off slowly into space. There practically all

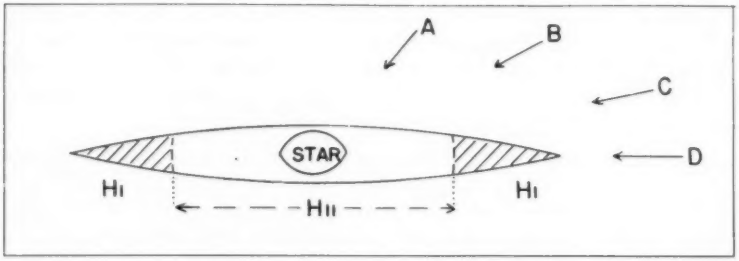


FIG. 2—Cross-section of Be star and its lenticular envelope. Arrows *A*, *B*, *C*, and *D*, indicate directions of view corresponding to profiles in figures 1 *A–D*.

hydrogen is neutral, but it is subject to strong Lyman-α radiation from within, and numerous atoms are excited to the second level and ready to absorb Balmer photons.

"Shell" Spectra. We see now why "shell" spectra are associated only with very wide emission lines. The H I region must lie in the line of sight between the observer and the greater part of the H II region, as well as the photosphere of the star. This will occur only if the observer is located within a few degrees of the equatorial plane. The outer gas is able to absorb strongly only from the central parts of the emission profile, since there is a velocity gradient in the envelope. The H I region has a lower rotational velocity than the H II region, and the limbs of the inner emitting cloud shine through because the neutral atoms in the line of sight are moving with velocities sufficiently different to shift their possible absorption frequencies entirely off the profile they receive. This is illustrated by figure 3.

Most attempts to compute theoretical emission and absorption profiles have been directed towards explanation of spectra of P Cygni type. Thus, Beals (1956) and Rottenberg (1952) calculated profiles for expanding scattering envelopes and for combinations of inner emitting and outer

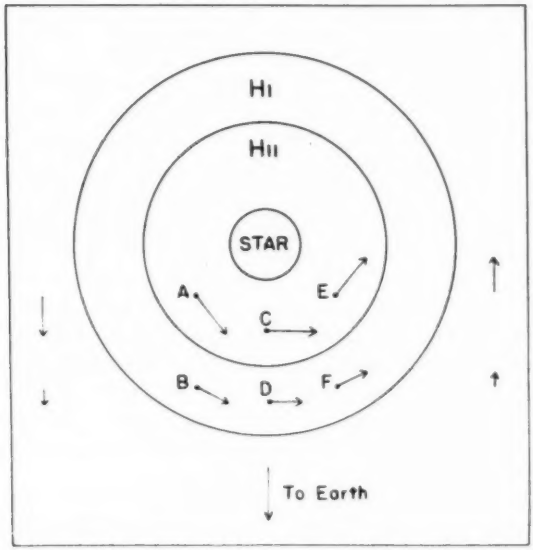


FIG. 3—Rotational model of a Be star. Line-of-sight velocity components at *A*, *B*, *E*, and *F* are shown at left and right. Atoms at *B* and *F* are unable to absorb radiation from *A* and *E* respectively, but atoms at *D* can absorb radiation from *C*.

absorbing shells with different velocities of radial expansion. The results matched rather well some observed profiles in P Cygni type spectra. A few profiles were calculated for a rotating scattering atmosphere. The results were qualitatively similar to the profile in figure 1 *C*. No calculations were made for the two-shell rotating model. Sobolev (1947) has determined profiles for an optically thick extensive rotating atmosphere, and the results are similar to figure 1 *C*. It is fairly obvious that a thick outer region of neutral hydrogen would produce the deep central absorption as shown in figure 1 *D*. The observed profiles of this type have a somewhat wide, flat-bottomed absorption, due to the spread of velocities of the atoms in the outer rotating region. Turbulence may play a part also in producing the broadening (Underhill 1954).

In addition to the lines of hydrogen, many shell spectra have weaker narrow absorption lines of Fe II, Ti II, and some other lines that are strong in α Cygni. Lines of Si II and Mg II do not appear strong in outer shells but evidently do occur in the inner parts of the envelopes of some stars. Occasional stars have a few lines of He I as sharp absorption, in striking contrast to the diffuse rotationally broadened lines from the

reversing layer. All the shell lines other than those of hydrogen are due to transitions in which the lower level is metastable. The strong α Cygni lines of Fe II and Ti II all fall in this category, as do also the conspicuous lines of Ni II at λλ4067 and 3769. The He I line λ3889 has for its lower level the metastable lowest triplet state, 2^3S. Two other He I lines that appear in shells are λλ3965 and 5015, both of which have the metastable 2^1S state as lower level. The H and K lines of Ca II appear in some shells, since they are resonance lines. The lines of Si II and Mg II, on the other hand, have non-metastable lower levels which are readily depopulated by transitions downward.

The theory of shell spectra was discussed by Struve and Wurm (1938) and later by Struve (1939). In the outer rarefied parts of the disk, where radiation is dilute, all normal levels are depopulated, but the metastable states retain roughly the same populations as in a reversing layer at the same excitation temperature. From the strengths of helium lines in shells, Struve and Wurm estimated that the dilution factors in shells are of the order of 0.01. This corresponds to a distance from the star of about 5 radii.

Indirect Test of the Rotating Lenticular Model. Recently Burbidge and Burbidge (1953*a*) have studied six Be stars that are seen roughly pole-on. Their results support the rotational model, and in particular the highly flattened form shown in figure 2. Without reviewing their entire study, it is worth while to examine the reasoning by which they reached their conclusion.

They found that observed profiles of the broad hydrogen absorptions had wider wings and slightly shallower centres than those of standard stars. Greater Stark effect would broaden the whole profile but would not cause the Be and B profiles to *cross* in the wings. Rotation modifies the profile appreciably only in the core, not in the wings. They suggest the profiles are modified by electron scattering. If so, the optical thickness of the scattering region must be between 0.2 and 0.4. To find the linear thickness, we must know the density.

In the spectrum of 11 Camelopardi the emission lines merge beyond H 22. From the Inglis-Teller formula

$$\log N_e = 23.26 - 7.5 \log n$$

(where n is the upper level quantum number of the last Balmer line resolved), the electron density in the emitting region is

$$N_e = 1.55 \times 10^{13}.$$

If it is assumed that the electron scattering takes place in part of the emitting region, the light path through the scattering region over the pole of the star, for optical depth 0.4, is only of order 0.01 of the stellar radius, which is taken as about 5 solar radii. In other words the pole-on view encounters only a very thin layer.

The equatorial extent of the emitting region can be evaluated within limits from measures of the total intensities of the emission lines. Using the electron density and an appropriate temperature in the Saha formula, it is found that only one hydrogen atom in 845 remains neutral, so that the density of neutral hydrogen is

$$N_H = 1.83 \times 10^{10} \text{ cm.}^{-3}$$

From the total intensities of the emission lines and the known transition probabilities, the total number of hydrogen atoms is calculated. Dividing by the density gives the volume of the emitting region:

$$V = (1 + x) \times 12.9 \times 10^{35} \text{ cm.}^3$$

Here x is an unknown correction for unmeasured emission (Lyman series, Balmer and Lyman continua, etc.). Extreme limits are obtained by setting $x = 0$ and $x = 100$. The resulting volumes, if assumed spherical, would have radii 2.1 or 9.4 times the stellar radius. For lenticular emitting regions, the extreme radii are 2.55 and 23.5 times the star. From a simple consideration of rotational velocity of the assumed ring, we found a minimum radius of 3.5 R_*. The spherical configuration seems to be ruled out by the required thinness of the polar electron-scattering region.

For the lenticular model, dilution factors at the outer edge of the lens are 0.08 or 0.002 corresponding to $x = 0$ or 100, respectively. These values "bracket" Struve's and Wurm's estimate of 0.01 based on the populations of the 2^1S and 2^3S states of He I. On the whole, the results are highly favourable to the flattened lenticular rotating model.

We now see a possible explanation of the washed-out appearance of the absorption lines in Be spectra, especially in the shell stars. We have to view the reversing layer through an atmosphere in which electron scattering redistributes the radiation in frequency, which has the effect of producing a continuum spread over the absorption lines. Where our view is most nearly edgewise, we have a very foggy view of the underlying absorption, as for example during the strongest shell stages of Pleione. But in most shell spectra we still see the absorption lines of the reversing layer clearly. If electron scattering operated so powerfully,

would we not lose sight of the star completely when we view the disk edgewise?

Perhaps the polar regions of the star would still be seen even in an edgewise view, and in a presentation that departed at all from edgewise, *one* of the poles would be relatively clear. On the other hand, it may be that the distortion of absorption profiles as measured by the Burbidges is due chiefly to another cause. They did not observe Hα. If they had, they might have suggested that a wider diffuse emission is responsible for the filling in of the central parts of the absorption profiles in Hβ and higher lines. In a number of Be stars Hα shows a broad hazy emission whose outer wings extend to two or three times the width of the better defined emission structure that appears at Hβ. If this is the main cause of distortion of the profiles, the role of electron scattering may be much less than supposed, though it is probably a contributing factor.

(*To be concluded*)

TIDAL-ELECTRIC POWER GENERATION

By F. Keith Dalton

Toronto Centre

The conversion of tidal energy into some other forms for the use and benefit of mankind is a matter of very practical astronomy combined with hydraulic, mechanical and frequently electrical engineering. In this present age, man is seeking every source of energy which he can transform economically and place under his control. Therefore, he is considering very seriously the feasibility of developing power from the ocean tides.

Energy for Mankind. For many millenia, our dependable sun has been man's chief source of energy supplying, directly or indirectly, his needs for sustenance and industry. Solar thermal radiation, after coming through the intermediate vacuous space, becomes effective not only in warming the surface of the earth but in promoting plant growth on which certain animals, birds and fish feed. Man, being both herbivore and carnivore, uses all of these for nourishment and finds further solar energy in vegetable life of past geological ages preserved in the forms of coal, oil and natural gases, and in rivers which result from evaporation and also in the wind which turns his windmills and propels his sailing ships. He applies these for his bodily requirements and his power needs. In each case, the sun is the steady and reliable fountainhead of energy.

There are, however, two other useful energy sources which are not attributed to solar radiation, namely, (*a*) atomic energy from terrestrial materials, a form that now is growing rapidly both in importance and in application, and (*b*) the tides which apparently will permit of economical exploitation for electric power supply.

It is estimated that for an average range of 2.3 feet all over the world the total power in the tides is 54,000 million horsepower while all of the power that can be developed from lakes and rivers on all continents would be only one seventh of that total. Is it any wonder then that the thought of obtaining power from the tides is most intriguing!

When ocean tides are considered, the moon becomes the most important factor, the sun now taking second place. These celestial bodies jointly, by mutual attraction with the waters of the oceans, produce this elusive tidal energy which man is endeavouring to harness and place at his service—and the earth's rotation on its axis serves to distribute this energy to all corners of all of his oceans and into the bays and estuaries.

Hydraulic Developments on Normal Rivers. In order to understand clearly the unusual problems that must be solved in tidal power developments, first consider the chief features of hydraulic plants on rivers which are not affected by tidal movements. Here there is a unidirectional flow due to a difference in level between two water surfaces. Either the current or the height of water, giving pressure, may be used to develop power. In some cases, both are used.

A few centuries ago, reciprocating water pressure engines, known as "rams", were employed to pump water to higher levels and, by combining three or more of these in proper phase relation, a rotary engine was produced which operated on pressure alone but these were of small size and ran at very low speeds. The most common form of water-motor for converting hydraulic power to rotating mechanical power, however, was the familiar and fascinating water-wheel. In those days, all power installations were isolated units used to drive grist mills or small factories.

By means of a supply channel, known as a "head race", water was led from the highest accessible level to the site of the water-wheel and, after giving its energy to the wheel, was led away by another channel at lower level, called the "tail race". The location of an abrupt natural fall of water was usually chosen as the site for such an installation. The vertical difference between high and low water levels was the "operating head" of water.

Two types of water-wheel were in general use, i.e. the "overshot" wheel for waterfalls ranging from 10 to 70 feet in height and the "undershot" wheel for waterfalls less than 10 feet high. The characteristics of these two wheels were somewhat different.

With the overshot wheel, water was projected over the top of the wheel and fell into buckets. Thus, by both impact and weight of water in these buckets loading one side of the wheel, mechanical rotation was produced. With the undershot wheel, water with appreciable velocity impinged upon the bottom blades and carried the wheel around. Impact due to the momentum of the water produced rotation.

These water-wheels on the old mill streams have been disappearing rapidly to be replaced by electric power as more economical in this modern age. Their open design renders them unsuitable for tidal power development anyway as they would be submerged during operation.

Hydraulic turbines for conversion of water power were introduced in 1827, in France. These enclosed wheels were driven by impulse or reaction when water met the blades on the "runner", the rotating member of the machine. The water was allowed to acquire considerable velocity before entering the turbine but within the turbine the velocity diminished and the change of momentum supplied the driving force.

When a hydro-electric generating station is to be built on a river, a dam is constructed for the dual purpose of raising the headwater level on the upstream side and creating a storage basin, virtually a lake in the river valley. The turbines are placed on the downstream side of this dam at or below tailwater level and drive the electric generators through vertical shafts, usually of short length. The generators would be below headwater levels though such is not necessary. Water from the high-level pond reaches the turbines by openings through the dam, an arrangement that is continued in tidal power plants. Hydraulic control equipment adjusts the loading of each turbo-electric unit automatically as station load varies.

In some cases where a high-level lake is available the water is led from this lake to the turbines through a sloping tube, a "penstock", or through artificially excavated rock tunnels. In tidal plants, however, the high pool and low pool, or low tide water, are separated by only the width of the dam, 150 to 200 feet, so neither penstocks nor rock tunnels are needed.

As a basis for comparison with the expected relatively low heads of water available at tidal power sites, the operating heads at some typical river plants in Ontario are here listed.

Location	River	Operating Head
		feet
Eugenia Falls	Beaver	554
Queenston	Niagara	294
Abitibi	Abitibi	237
Barrett Chute	Madawaska	154
St. Lawrence Development	St. Lawrence	81
Chats Falls	Ottawa	53
Ragged Rapids	Muskoka	38
Bala	Muskoka	19
Sills Island	Trent	14

Each of these stations has several turbo-electric units, the alternating-current generators of which operate in synchronism with one another and divide among themselves the total load of the plant. Where several hydro-electric generating stations are connected to one network, parts of the load are shifted from one to another to conserve water when and where necessary. Such transferring of appreciable amounts of load among generating stations will be an inherent feature, and frequent daily routine, wheresoever tidal-electric power developments are involved.

The Tides. The ocean tides are movements of the waters, rising and falling in rhythmic oscillation with an average period of about 12 hours,

25 minutes (figures 1 and 2), and also flowing into and ebbing out of all accessible bays and rivers. They are caused by gravitational attraction between the moon and sun on one hand and the waters of the oceans on the other by which the latter are drawn westward and eastward as the earth rotates on its axis. The moon produces the most noticeable tidal effect but the sun's force, about 46 per cent. of that of the moon, interferes with the lunar control. The lunar force is greatest with the moon in perigee, and least when it is in apogee, whereas the solar force is maximum at the equinoxes and least at the solstices.

There are three types of tide or, rather, three chief factors which are present in all tides but one or other appears most prominent according to the geographic location considered. These factors depend separately upon the phase, distance and declination of the moon. The tides are known, respectively, as "synodic", "anomalistic" and "declinational". Highest synodic tides occur when the moon and sun are in conjunction or in opposition, highest anomalistic tides when the moon is in perigee

FIG. 1—Fundy low tide at Eastport, Maine (Passamaquoddy area), at elevation 0.00—low water datum. Note the floating wharves, at left, with their ramps at very steep angle. (U.S. Army Corps of Engineers.)

FIG. 2—Fundy's prodigious high tide at Eastport, Maine, at elevation 28.2 feet—extreme maximum high water. Note the tidal eddies as the water reaches final flood level and the floating wharves with their ramps nearly horizontal. (U.S. Army Corps of Engineers.)

and the maximum declinational tides with the moon nearest to the zenith or nadir.

Successive synodic tides vary somewhat in height, appearing uniform only near the times of the "quarter moons", figure 3(*a*), whereas successive anomalistic tides usually are much more uniform at all times, figure 3(*b*), remarkably so in the Bay of Fundy and Hudson Strait. Both of these types of tide are considered suitable for power development—as examples, synodic tides on the west coast of France and anomalistic tides in the Bay of Fundy.

Successive declinational tides, however, vary so greatly in amplitude that when the moon is in highest declination there is only one tide per day—one high tide *or* one low tide—and then the water remains at the opposite level—low or high, respectively—for about 18 hours with only relatively small oscillations, figure 4(*b*) and (*c*). The extreme effect occurs when both moon and sun are at their highest declinations at the same

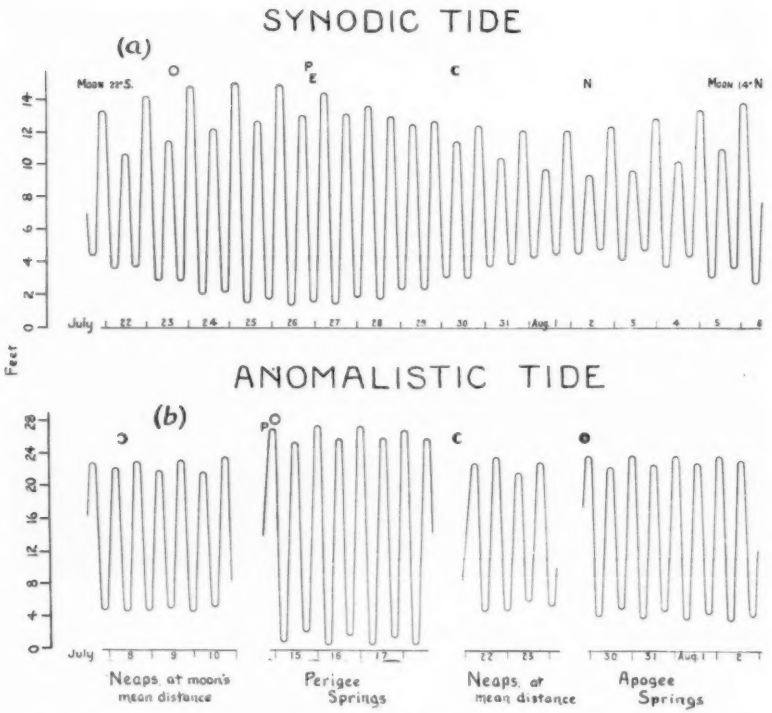


FIG. 3—Variation in amplitude of successive tide cycles, types which appear suitable for power development. (*a*) *Synodic tide* at Father Point, Que., from full moon to new moon. (*b*) *Anomalistic tide* at Saint John, N.B., showing remarkably uniform levels with range according to the moon's distance.

Moon's phases are denoted by usual signs; *P*—moon in perigee; *E*—moon on equator; *N* and *S*—moon at maximum declination north or south; "Springs"—the higher tides, any type, at new or full moon; "Neaps"—the lesser tides, any type at moon's quarters. (From *The Tides and Tidal Streams* by W. Bell Dawson, Supt. of Tidal Surveys, Ottawa.)

time, figure 4(*c*). Uniformity appears for a brief period when both moon and sun are on the equator, figure 4(*d*). This very variable type of tide is not considered suitable for power development on account of its diurnal inequalities.

Declinational tides are found along the east coast of New Brunswick, on the shores of Prince Edward Island, in the Strait of Georgia at Victoria, B.C., in the Gulf of Aden, at Hong Kong and at other locations on the coasts of the Pacific Ocean. The writer had an excellent oppor-

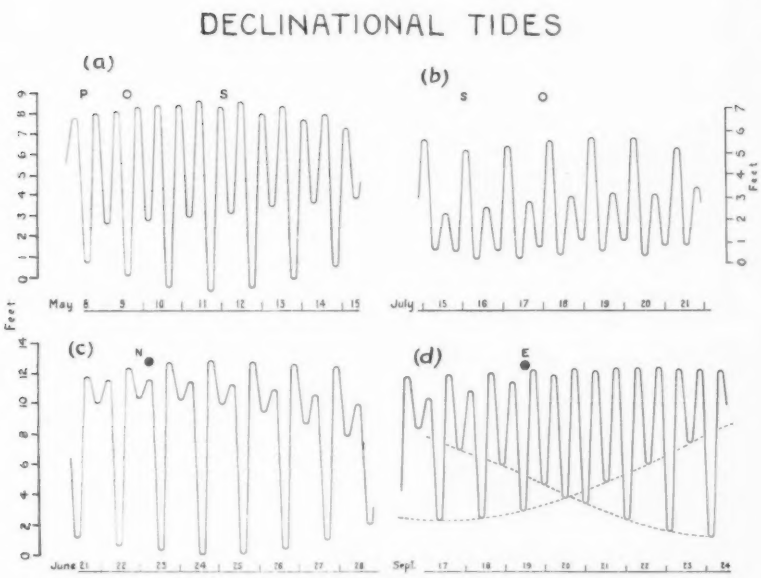


FIG. 4—Variation in amplitude of successive cycles of *declinational tides* under different conditions. These tides are not considered suitable for power development due to diurnal inequalities. (*a*) Inequality in low water at Charlottetown, P.E.I., with moon in maximum south declination. (*b*) Inequality in high water at Caraquet, N.B., with moon in maximum south declination. (*c*) Extreme inequality in low water in the Strait of Georgia, B.C., with both moon and sun at their maximum north declinations. (*d*) Brief uniformity in the Strait of Georgia with both moon and sun on the equator. (From *The Tides and Tidal Streams* by W. Bell Dawson, Supt. of Tidal Surveys, Ottawa.)

tunity to observe an extreme case at Percé, Quebec, where the tides remained continuously so low for all of the daylight hours on one day, figure 4(*b*), that the stony path from the mainland out to Percé Rock was high and dry, and thus usable all of this time, whereas on other days at high tides there is a depth of 2 to 3 feet of water over this path so one then must wade through it to reach the Rock.

Incidentally, the three types of tide occur within 60 miles of one another on the shores of Nova Scotia, namely, synodic tides along the Atlantic coast, anomalistic tides in the Bay of Fundy and Minas Basin with declinational tides in the Northumberland Strait. It seems rather mysterious too why the tides in Hudson Bay should be synodic while those in Hudson Strait are anomalistic, and of very high range, for at those latitudes one could expect a strong declinational component.

When a tide of any type meets a coast line, or its travel is impeded by some other obstacle, the water level rises. This is particularly evident when it enters a bay with a wide mouth and converging shores such as the Bay of Fundy or Baie St. Michel on the north-western coast of France. In each of these, the range at the head of the bay is about 25 feet higher than at the mouth. Here the phenomenon of resonance plays a large part in amplifying the tidal range. As these are regions of exceptionally high and fairly uniform tides, they have been studied carefully as possible sites for tidal-electric development.

In strong contrast to these, there are many locations where the range of the tides is remarkably low—only a few inches at Nantucket Island, for example. In the Northumberland Strait the declinational tides are relatively low and make Shediac Bay an unusually quiet harbour but these tides would not be worth while for power.

Polar conditions are interesting but useless for power. At the north pole there are no semi-diurnal travelling tides but slight, 1.5-foot, bi-weekly* and semi-annual cyclic variations in water levels according to the declinations of the moon and sun. The south pole, of course, is inland on a continent around which low semi-diurnal tides, 3 to 4 feet in range, continue to circle, from east to west, with bi-weekly* and semi-annual variations.

The Island of Tahiti evidently is in a unique location. It seems to be at the node of a lunar-influenced oscillating basin in the Pacific Ocean so here the sun has full control of such small tides as there are, producing the "high tides" regularly at noon and midnight with "low tides" at 6:00 o'clock, a.m. and p.m.

Practically everywhere, with probably only this exception, the tide schedule is at variance with daily routine in civil life. The tide cycles each day are, on the average, about 50 minutes later than on the previous day so tidal power can not be used regularly for peak load assistance which usually must be given at about the same hours every day. This is one of the serious handicaps when using the tides for power.

Due to molecular friction in the water and surface friction in the estuaries, the period from high tide to low tide ordinarily is somewhat longer than that from low to high tide. On the west coast of England, e.g. the Bristol Channel with a 47-foot tide, these periods happen to be practically equal. In the accompanying graphs, however, the tides are shown simply as sinusoidal oscillations.

*"Bi-weekly" means half of the lunar declinational month of 27.2 days, average, i.e. 13.6 days.

At any given location the period of an individual tide cycle—taken as average of 12 hours, 25 minutes—varies with the changing phases of the moon, its angular velocity in orbit and other factors. High waters always occur later than the new or full moon's crossing of the local meridian, the mean lapse of time being known as "the establishment of the port". For New York, this interval is 8 hours 13 minutes.

The above friction factors in the tides also are causing very slight deceleration of the earth's rotation and corresponding acceleration of the moon in travel in a spirally expanding orbit. French scientists have made calculations to determine to what extent the construction of dams in some estuaries would affect these phenomena and have come to the conclusion that the effects would be quite negligible.

It must be realized then that tidal movements are very complex involving not only the influences of the moon, sun and earth, the shapes of the continents and the depths of the oceans and water passages, but also friction and wind influence. Some of these factors are not fully understood, so calculated predictions on tides may not be as accurate as those for eclipses, transits and occultations. Modern electronic computers, however, facilitate these calculations and they can make predictions with a very high degree of accuracy.

While the terms, synodic, anomalistic and declinational, designate the variety of types of tide, the prediction of tides is based upon analysis of previous measurements into harmonic sinusoidal components—semi-diurnal, diurnal, bi-weekly, monthly, semi-annual and annual—for each given location, the calculation of value of each harmonic at a given time and then the synthesis of all components to obtain the resultant predicted tide. Tidal forces are recorded as to the magnitude and phase of their harmonics rather than according to the type of tide.

There is another phenomenon, wrongly named a "tidal wave"—an unexpected and powerful single travelling wave which has its origin in some seismic disturbance of the nature of an earthquake under the ocean bed or in a hurricane. This type of wave which wreaks such havoc both at sea and at the shore, is neither predictable nor periodic and must not be confused with the usual ocean tides.

Tidal Power Development in General. A rising tide is a mounting head of water with increasing potential energy which may be converted into other forms. If a suitable low-level pond or tail race can be found or established, the high tide can be used to drive hydraulic turbines but such a restless elusive source of energy presents problems which are

decidedly difficult in comparison with those of the ordinary hydro-electric river stations with their relatively steady operating heads of water.

The first problem in tidal power development then is to obtain as high and steady an operating head as possible. The ideal, however, is not possible of attainment with presently proposed methods, the maximum instantaneous head for all approved methods now being about the same—only 80 per cent. of the range of the tide on any particular cycle. The average operating head, nevertheless, improves with some changes in the scheme adapted. There is not likely to be much doubt as to the sufficiency of water available for any of the projects in mind in the Bay of Fundy or on the north-west coast of France.

The power that it is theoretically possible to obtain from any water motor—water-wheel or hydraulic turbine—is the product of the head of water and the discharge through the turbine. If the head be measured in feet and the discharge in pounds of water per second, then a product of 550 is one horsepower; a product of 737.3 is one kilowatt, an electrical term. Friction and eddies in water channels and in turbines reduce the output much below the theoretical figure so designs aim at minimizing these losses to increase the efficiency of the installation.

The varying water level of the tides must in some way be converted to more steady conditions such as the filling of a large storage basin at high tide and having the low tides or a low level basin provide the tail race. The operating head of water at any moment then is the vertical difference between the high and low water levels. The average head may be only 20 feet, quite low compared with heads available in many river plants.

For power development, the highest tide ranges are required and tides must be nearly uniform in both their high and low levels in successive cycles. Synodic and anomalistic tides can be used but preferably the latter. Declinational tides do not appear satisfactory, as already explained.

In calculating tidal power available at any site, the term "coefficient of the tide" is used to express the relative range. Typical coefficients are as follows:

120 : exceptional equinoctial high tides,
100 : average equinoctial high tides,
95 : average high tides,
70 : average tides,
45 : average low tides,
20 : more feeble low tides.

Under equinoctial conditions, the basis of these coefficients, the sun is at its average distance from the earth and at zero declination.

In addition to the Bay of Fundy in the Canadian maritime Provinces and Baie St. Michel in north-western France, there are but few other locations where conditions are considered suitable for development. These include the Severn estuary on the west coast of England, Mezen and Penzhina Bays in Siberia, Cook Inlet in Alaska and some sites along the coast of Argentina where the waters pile up, being carried on by their momentum when the west-bound tides from Australia pass the Cape of Good Hope, the southern tip of Africa, and turn to travel northward up the Atlantic Ocean. Full use of all known possible locations, however, would produce only 1/500th part of the world's needs for power—and some of the good sites, such as Frobisher Bay with 40-foot anomalistic tides, are too remote from populated and industrial centres where power can be sold. The Province of Manitoba has two distant sites with 16-foot synodic tides—Chesterfield Inlet and Port Nelson, both on the west coast of Hudson Bay.

Two basic systems have been proposed for tidal power development on a large scale using hydraulic turbines, namely, the "one-pool" and "two-pool" schemes. The first of these has a single dam separating the pool, or basin, from the sea. The second method requires three dams to separate a high pool, a low pool and the sea from one another. There are gates in the dams to allow adjustment of water levels according to the phases of the tides and also locks for the passage of ships into and out of the basins.

Complete interruptions of power in every tide cycle are inherent in the one-pool system whereas continuous power is obtained from the two-pool scheme but both suffer from very wide variations in the amount of power available at any moment. An auxiliary power plant therefore is absolutely necessary in either case to stabilize conditions in the supply for consumers' use. Otherwise the variations and specially the interruptions in power delivery by a tidal station could not be tolerated in industrial and domestic loads. The auxiliary generating station may be either hydraulic or thermal and may be located at a reasonable distance, preferably nearer to the load centre.

France appears to prefer the one-pool system which requires only a single estuary or single bay and is proceeding with a development on this basis while the two-pool method seems to be favoured in Canada and the United States of America where two confluent rivers in one location, and two adjoining bays at other sites permit this type of operation using the exceptionally high tides of the Bay of Fundy.

(To be concluded)

CANADIAN SCIENTISTS REPORT—XXIV

THE STELLAR POPULATION OF THE GALACTIC NUCLEUS

By Sidney van den Bergh

David Dunlap Observatory, University of Toronto, Richmond Hill, Ontario

Abstract

Available evidence indicates that the dominant population of the galactic nucleus does not consist of stars similar to those occurring in halo-type globular clusters (population II). Star counts in the direction of the nucleus appear to show that the luminosity function of the galactic nucleus increases rapidly in the range $0 < M_{pg} < +1$. It is suggested that this increase may be due mainly to giants of spectral types G and K. Only about 2 per cent. of the giants are of type M. It is shown that approximately 15 per cent. of the M stars in the nucleus are variables with amplitudes larger than 0.5 mag. and that, excluding Mira stars, none have amplitudes larger than 1.5 mag. Semi-quantative arguments indicate that the majority of the eclipsing variables observed in the direction of the nucleus are foreground stars.

Vast absorbing dust clouds, which are concentrated close to the galactic plane, completely obscure the galactic nucleus to observers on earth. Only in a few relatively dust-free "windows" is it possible to observe parts of the lens-shaped nuclear bulge of the galaxy, which extends above and below the galactic plane. But even in these windows, interstellar absorption is considerable. It is, therefore, not surprising that the first information on the type of stellar population which occurs in the nucleus, was obtained by studies of the nuclear region of the Andromeda Galaxy, which is believed to resemble our own Milky Way System in a number of respects.

In 1943, the late Walter Baade (1944) succeeded in resolving the amorphus nuclear region of the Andromeda Galaxy into swarms of very faint stars on red-sensitive plates exposed with the Mount Wilson 100-inch reflector. From his observations Baade concluded that the brightest stars in the nuclear region of the Andromeda Galaxy were quite red and had an absolute magnitude $M_{pg} \simeq -1$. Since the brightest stars in globular clusters are also red and have absolute magnitudes of about $M_{pg} = -1$, Baade concluded that the population of the nuclei of intermediate-type spiral nebulae, like the Andromeda Galaxy and the Milky Way System, were probably very similar to those of globular clusters.

The first observations of stars in the nucleus of our own galaxy were also obtained by Baade (1950) who, in collaboration with S. Gaposchkin (1956) made an exhaustive study of the variable stars in a small low absorption window surrounding the globular cluster NGC 6522. This cluster, which has galactic co-ordinates $l = 328.°2$, $b = -4.°3$, is located within a few degrees of the galactic nucleus at $l = 327.°7$, $b = -1.°4$. More than 100 RR Lyrae type variables were found in the star field studied by Baade and Gaposchkin. Since RR Lyrae stars occur frequently in globular clusters, Baade regarded this observation as a confirmation of his hypothesis that the galactic nucleus consists of globular cluster stars.

The distribution of the apparent median photographic magnitudes, $\bar{m}_{pg}$, of these RR Lyrae variables is shown in figure 1. The figure shows a sharp maximum in the distribution at $\bar{m}_{pg} = 17.5$, which probably corresponds to the point where the line of sight intersects the nuclear

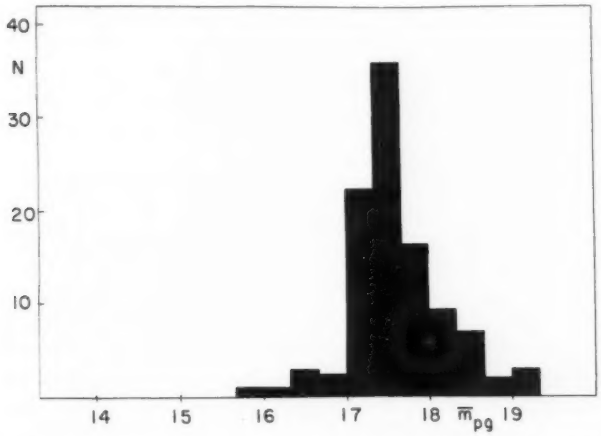


FIG. 1—The distribution of the median magnitudes of 104 RR Lyrae stars in the variable star field studied by Baade and Gaposchkin. The sharp maximum at $\bar{m}_{pg} = 17.5$ is probably due to RR Lyrae stars in the nuclear bulge of the galaxy.

bulge of the galaxy. Assuming $\bar{M}_{pg} = +0.5$ for the RR Lyrae stars in the nucleus one obtains a distance modulus $m - M = 17.0$ for the galactic nucleus. The fact that the distribution of the apparent median magnitudes of the RR Lyrae stars has such a sharp peak at $\bar{m}_{pg} = 17.5$

implies that the RR Lyrae stars must have a strong concentration to the galactic nucleus and a relatively small dispersion in intrinsic luminosity. That RR Lyrae stars show a strong concentration to the nucleus does not necessarily imply that a globular cluster-like population is dominant in the galactic nucleus. In fact it may be shown that the number of RR Lyrae stars observed in the direction of the nucleus may be accounted for, if only a few per cent. of the population of the nucleus is similar to that of typical halo globular clusters.

Spectra of the nucleus of the Andromeda Galaxy, which is probably similar to the nucleus of the Milky Way System, have been obtained by Morgan and Mayall (1957). These spectra do not exhibit the extreme metal deficiency which characterizes the majority of the halo globular clusters. This observation shows that globular cluster-like stars do not emit the major portion of the light of the nucleus of the Andromeda Galaxy.

Some information on the dominant population in the galactic nucleus may be obtained from star counts in Baade's field surrounding NGC 6522. Such counts have been made on reproductions of one of Baade's plates of this region, which have been published by Nassau and Blanco (1958). These counts, which are plotted in figure 2, were made in an

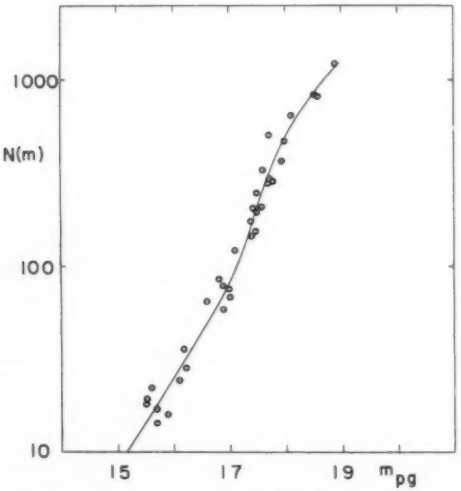


FIG. 2—Number of stars per quadrant, $N(m)$, brighter than magnitude m in the direction of the galactic centre. The sharp increase in the star counts between 17th and 18th magnitude is possibly due to stars in the nuclear bulge of the galaxy.

annulus centred on NGC 6522, with inner and outer radii of 4 cm. and 8 cm. on the print (1 cm. $\simeq 0.'8$). Outside this annulus star images are affected by coma and inside it an appreciable contribution to the counts is given by members of NGC 6522. (The south-west quadrant of the annulus was not counted because the stellar images are of lower quality than those in the other quadrants.) Figure 2 shows that $N(m)$, the number of stars per quadrant brighter than m, increases sharply between 17th and 18th magnitude. If real, this effect may be accounted for by assuming that the luminosity function of the galactic nucleus increases rapidly between $M_{pg} = 0$ and $M_{pg} = +1$. It should however be emphasized that the reality of the sudden increase in the star counts between 17th and 18th magnitude depends in a rather critical way on the assumption that Baade's magnitude scale, which depends on photographic transfers, is not subject to systematic errors. Taken at face value the data plotted in figure 2 indicate that there are about 300 stars with $0 < M_{pg} < +1$ within each quadrant of the annulus. According to observations by Nassau and Blanco (1958), there are on the average only six M stars per quadrant in this magnitude range. In view of Morgan and Mayall's (1957) observation that "cyanogen giants" of spectral types G and K provide the major contribution to the light of the nuclear region of the Andromeda Galaxy, it appears probable that the majority of the stars contributing to the luminosity function of the galactic nucleus in the range $0 < M_{pg} < +1$ are stars of spectral type gG and gK.

Some additional information on the brightest stars in the nucleus can be obtained from Gaposchkin's (1956) exhaustive study of the variables in the field surrounding NGC 6522.

Eclipsing variables. 39 eclipsing variables have been found in the field studied by Baade and Gaposchkin. The question arises whether these variables are located in the galactic nucleus or whether they are merely foreground stars which appear projected on the nucleus. This question may be answered in a provisional way by considering the relation between the period and the luminosity of eclipsing binary stars. If an eclipsing variable has a short period, say of the order of one day, then the separation of the components must be small and hence the components must have small radii. If, on the other hand, one considers eclipsing binaries with long periods, say of the order of 10 years, then no restriction is placed on the radii of the components. However, geometrical considerations make it overwhelmingly probable that one of the components of such an eclipsing system is a star of very large radius, i.e. a late type giant or supergiant star. Making use of this fact and making the plausible assumption

that the nucleus does not contain stars of spectral types O and B, it may be shown that the overwhelming majority of the eclipsing variables in the direction of the nucleus are actually foreground objects of the galactic disk population. Only one star, namely V 1319 Sgr, is probably located in the nucleus.

Intrinsic variables. Excluding RR Lyrae stars, which have been discussed previously, Gaposchkin finds the following numbers of intrinsic variables in the field surrounding NGC 6522:

Semi-Regular	(*SR*)	67
Irregular	(*I*)	15
RV Tauri	(*RV*)	8
Mira	(*M*)	20

Two lines of evidence show that the stars which Gaposchkin classifies as *RV* are not true RV Tauri stars.

(*a*) The RV Tauri stars in the vicinity of the sun have spectral types F, G and K, whereas spectroscopic observations by Nassau and Blanco (1958) show that the stars classified as *RV* in the nucleus have spectral type M.

(*b*) All stars classified as *RV* in the nucleus have amplitudes < 1.0 mag., whereas 97 per cent. of the RV Tauri stars in the vicinity of the sun have amplitudes ≥ 1.0 mag.

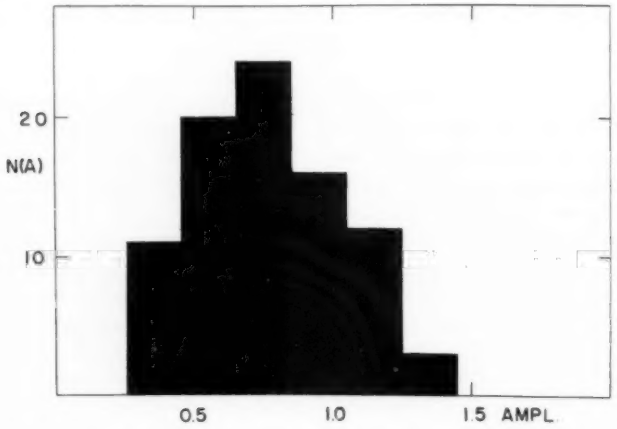


FIG. 3—Frequency of light amplitudes among the red variables in the nucleus. Note the cutoff at $A_{pg} = 1.5$ magnitudes. The small number of variables with $A_{pg} < 0.5$ magnitudes is probably due to incompleteness of the data.

The stars which Gaposchkin classifies as Irregular do not differ from those classified as Semi-Regular in amplitude, spectral type or frequency of apparent magnitude. It therefore appears probable that the stars classified as *SR*, *I* and *RV* in the nucleus form a uniform group. The frequency with which different light amplitudes occur among the members of this group is shown in figure 3. The figure shows that all the red variables in the nucleus (excluding Mira stars) have amplitudes smaller than 1.5 magnitudes. The decrease in the frequency with which amplitudes less than 0.5 magnitudes occur suggest that the variable-star data are incomplete for small amplitudes. It appears quite possible that all stars with M-type spectra in the nucleus are variables, but that only those with relatively large amplitudes have been detected as variable in light. This hypothesis receives support from a comparison of the distribution of the median magnitudes of the *SR*, *I* and *RV* variables and the distribution of the magnitudes of all stars of spectral type M (excluding Mira stars) within 11.′2 of NGC 6522, which is shown in figure 4. The figure shows that the distribution of the magnitudes of the M stars and the variables is quite similar. The more rapid decrease in the number of M stars fainter than $m_{pg} = 18.0$ is probably due to the fact that incompleteness in the M-star data of Nassau and Blanco sets in at a somewhat brighter magnitude that it does for the variable-star data. A comparison of the distribution of the apparent magnitudes of RR Lyrae

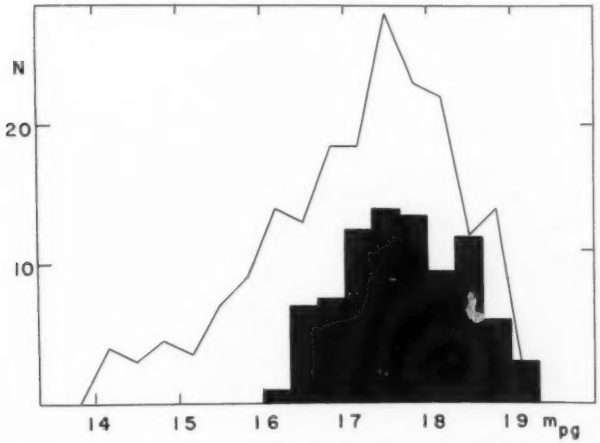


FIG. 4—The figure compares the distribution of the median magnitudes of the red variables in the direction of the galactic centre (lower curve) with the magnitude distribution of *M*-type stars within 11.2′ of NGC 6522 (upper curve).

stars (figure 1) with that of the M stars (figure 4) shows that both distributions have a maximum at $m_{pg} = 17.5$ but that the RR Lyrae stars show a much smaller dispersion about this maximum than do the M stars. The fact that both distributions have their maximum at $m_{pg} = 17.5$ probably means that the absolute photographic magnitudes of RR Lyrae stars and stars of spectral type M are approximately equal. The large scatter of the M stars about the maximum may be due to two factors: a relatively large dispersion in absolute magnitude and (or) a relatively small degree of concentration to the galactic nucleus.

The properties of the stars of spectral type M in the nucleus (excluding Mira stars) may perhaps be summarized as follows:

(*a*) The M stars in the nucleus have $M_{pg} \simeq +0.5$.

(*b*) Approximately 15 per cent. of these stars are variable with light amplitudes larger than or equal to 0.5 magnitudes.

(*c*) In no case do the light amplitudes of the M-type variables in the nucleus exceed 1.5 magnitudes.

It would be of great value to our understanding of the evolution of the galaxy to know if such M stars also occur in the vicinity of the sun, or whether they are peculiar to the nuclear region of the galaxy.

The observational evidence which is now available on the stellar population of the nucleus may tentatively be summarized as follows:

(1) The dominant population of the nucleus does not consist of stars similar to those occurring in halo-type globular clusters.

(2) The number of stars brighter than $M_{pg} = 0$ is small.

(3) The luminosity function of the galactic nucleus appears to increase rapidly in the range $0 < M_{pg} < +1$.

(4) If real, this increase is probably due to "cyanogen giants" of spectral types G and K.

(5) Approximately 2 per cent. of the giants in the nucleus are of spectral type M.

(6) About 15 per cent. of these M-type stars are variables with amplitudes larger than half a magnitude. In no case do the nuclear M-type variables (excluding Mira stars) have amplitudes larger than 1.5 magnitudes.

References

Baade, W. 1944, *Ap. J.*, vol. 100, p. 137.
Baade, W. 1950, *Publ. Univ. Michigan*, vol. 10, p. 7.
Gaposchkin, S. 1956, *Variable Stars* (U.S.S.R.), vol. 10, no. 6.
Morgan, W. W. and Mayall, N. U. 1957, *Publ. A.S.P.*, vol. 69, p. 291.
Nassau, J. J. and Blanco, V. M. 1958, *Ap. J.*, vol. 128, p. 46.

VARIABLE STAR NOTES

By Margaret W. Mayall

The American Association of Variable Star Observers, Cambridge, Mass.

The Springfield (Mass.) Museum of Natural History once again was host to the A.A.V.S.O. at its Annual Meeting on October 14–15, 1960. Mr. Frank Korkosz, the Director of the Museum, gave a welcome that made us feel as though we were really at home.

The feature speaker of the meeting was our own member, Cyrus F. Fernald, who made his 100,000th variable star observation on June 27, 1960. Mr. Fernald talked about "Footsteps on the Way to 100,000 Observations," and started a general discussion of observing problems. As far as we know, only two other amateurs have reached the 100,000 goal: Albert F. Jones of Timaru, New Zealand, and our own Reginald de Kock of Capetown, South Africa. Several other members are well on their way toward the goal, and may reach it within a few years. Mr. Fernald attributes much of his speed in observing to the use of his Springfield mount. He figures it takes him 20 to 30 seconds to locate and observe a variable, and another 20 to 30 seconds to record the observation. He saves nearly half a minute if he observes 2 stars and then records them (not recommended unless you have an excellent memory!). Mr. Fernald has been known to make and record observations of 60 variables in one hour.

At the business session, Peter M. Millman and John J. Ruiz were re-elected to 2-year terms on the Council, and Robert M. Adams and Robert Brady were elected to fill the vacancies left by two retiring members. The Council announced election of officers for the coming year as follows: President, Clinton B. Ford; 1st Vice-President, Dorrit Hoffleit; 2nd Vice-President, William G. Cleaver; Director, Margaret W. Mayall; Secretary, Clinton B. Ford; Treasurer, Percy W. Witherell; Clerk, R. Newton Mayall; Auditor, Cyrus F. Fernald. Joseph A. Anderer was elected by the Council to fill the place left vacant by Mr. Cleaver. We were very pleased to have our good Secretary, Mr. Ford, consent to take the office of President for this our 50th Anniversary year. We would not let him give up his Secretaryship and insisted he could use both hands for signing official papers.

Twenty-four applications for membership were approved by the Council: three sustaining and twenty-one annual. Elected to Sustaining membership were: Richard Hamilton Davis, *Massachusetts*; Theodore Gomperz, *New York*; and Harvey Hepworth, *New York*. Newly elected annual members are: Carl A. Anderson, *New Hampshire*; Charles Howard Belcher, *Virginia*; David L. Babcock, *Indiana*; Gary Bream, *Pennsylvania*; Robert Brown, *Texas*; Stephen E. Burt, *Massachusetts*; Carbide's "Questeers" Amateur Astronomical Society, *West Virginia*; Robert R. Conklin, *Virginia*; John S. Drilling, *Illinois*; David Andrew Dumm, *Ohio*; John Likley, *New York*; Charles Morris, *New York*; Everett O. Morrow, *California*; A. Thomas Murphy, *California*; Rev. Alphonse Oberstatter, *Moselle, France*; Wayne B. Persons, *Massachusetts*; Robert Johan

Rosenvold, *Colorado*; Herbert O. Seavey, *Arizona*; Claude Smith, *Ohio*; James Roy Thompson, *New York*; and Neil Maurice Travis, *Michigan*.

Miss Helen M. Stephansky, who has resigned after a number of years as our A.A.V.S.O. assistant, was presented with life membership in the Association.

The following members died during the year: Francis W. Collins, of Ridgefield, Connecticut, a life member since 1932; Mrs. Rosina Dafter, Queensland, Australia, a member and observer since 1920; Bernhard H. Dawson, La Plata, Argentina, a Charter Member (1917) and active observer; Alice Farnsworth, formerly of Mt. Holyoke College, a life member since 1921, an active observer and former President of the A.A.V.S.O.; Samuel A. Mitchell, formerly of Leander McCormick Observatory, who was made an honorary member in 1919, and who set up many of our faint variable star sequences; George Nolte of New York and Massachusetts, a Charter Member (1915) and former observer; Patrick O. Parker, Griffin, Georgia, a past officer and an active observer; and Milford W. Wall, a member since 1950.

An exceptionally fine and varied group of papers was presented during the meeting. Summaries of these are published in the A.A.V.S.O. Abstracts. Among the subjects covered were: *Evolution in Classification* by Meredith Baldwin, a student at Wellesley College, who made a very interesting study of the way the RW Aurigae type stars have been classified in catalogues; *Observations of Jupiter* by Charles Morris, one of our youngest new members, who commented on the changes in brightness and apparent size of Jupiter over several months; *Halo Phenomenon*, a description of an unusual elliptical halo by Herbert Luft; *Solar Prominences*—some beautiful time-lapse colour movies of prominences by Walter Semerau; *Conjunction of Vega and Echo*, as observed by James H. Carlisle, III, on September 12, 1960; and *Identification of Nova Herculis 1960* on the plates of the National Geographic Society—Palomar Observatory Sky Survey, by Thomas A. Cragg, who found the nova to be the middle and northern of a close triple. It showed a variation of about 2 magnitudes on two sets of the Schmidt plates. The measured position of the nova was $18^h\ 52^m\ 44.^s68,\ +13°\ 06'\ 32.''9$ (1900). *Some of My Best Friends are Astronomers* by Srta. Consuelo M. Ruiz, was presented in her absence by her brother John, in the form of colour slides and a tape-recorded talk. Joseph Ashbrook talked about the Algol-type variable *RZ Cassiopeiae* and asked for observations; Charles H. Giffin sent a paper to be read in his absence on *The Practicability of Coloured Filters for Visual Photometry*, which told of his experiments with various filters, and a plea for other observers to co-operate on a programme with him in using the Kodak Wratten 57 filter; Harvey Hepworth exhibited his remarkable photographs of *Sun-spots*; Casper Hossfield spoke on *Sudden Enhancements of Signals (SES)*, and showed examples of correlations between the SES's and SEA's. Margaret Mayall showed a light curve of *Nova Herculis 1960* and a complete curve of *R Coronae Borealis* from 1845 to 1960; and Peter M. Millman gave a progress report on *The Canadian I.G.Y. Meteor Programme*, and showed slides of equipment and methods of tabulation.

After the society dinner, John and Sara Welch showed very beautiful colour slides with running commentaries on their most interesting trip by automobile to Alaska.

The Annual Report of the Director showed that 58,791 individual observations of variable stars plus over 14 hours of constant watch of flare stars, were received from 234 observers in 1,002 reports, an average of about 84 reports each month. The number of observers was the greatest in the history of the A.A.V.S.O. The next highest number per year was 217 in 1935: an interesting coincidence, for we had a bright nova in Hercules in 1935 and another one in 1960! Ninety-two observers in 18 countries outside the United States made about 46 per cent. of the observations.

Observations received during September and October 1960: A total of 9,235 was received: 4,689 from 105 observers in September, and 4,546 from 81 observers in October.

Observers	Sept.		Oct.		Observers	Sept.		Oct.	
	Var.	Ests.	Var.	Ests.		Var.	Ests.	Var.	Ests.
Adams, R. M.	88	158	94	170	Jones, A. F.	22	68	..	..
Anderson, Carl	6	18	7	13	Kelly, F. J.	17	28	13	22
Anderson, Curtis	48	73	205	307	Knowles, J. H.	16	19	13	30
Axelson, K.	6	13	5	8	Kopp, R.	..	..	11	27
Ayala R., H.	21	89	15	42	Lacchini, G. B.	35	153	33	116
Ball, A. R.	15	25	..	..	Lattey, M.	21	40	22	62
Barroso, J. J.	16	48	2	2	Lewindon, F.	..	..	1	3
Bartha, L.	1	2	..	..	Loblay, R.	1	2	..	..
Bash, D.	17	17	..	..	Lovi, G.	..	..	4	4
Bateson, F. M.	4	5	..	..	Lucas, D.	5	5	4	10
Berg, J.	14	34	..	..	Lynch, J. S.	9	9	..	..
*Berg, R.	..	..	13	14	Mayall, M. W.	1	2	..	..
Bradley, D. A.	21	21	56	69	McFarland, T.	52	104	..	..
Brady, R. F.	..	..	35	37	McPherson, C. A.	38	50	34	42
Braune, W.	..	..	28	203	McWilliams, A.	1	2	..	..
Bream, G.	..	..	2	2	Mende, R.	..	..	5	50
Breckinridge, J.	59	145	..	..	Meynet, A.	4	19	..	..
Brown, R. P.	5	5	..	..	Miller, R. W.	4	4	..	..
Buckstaff, R. N.	17	48	..	..	Miller, W. A.	20	20	35	52
Burt, S. E.	11	29	36	97	Montague, A. C.	20	20	22	28
Byrd, J.	5	5	..	..	Morgan, F. P.	15	23	15	17
Byrd, W.	5	5	3	3	Morrison, R.	1	1	..	..
Carlisle, J. H.	..	..	5	9	Mourilhe S., P.	17	55	14	31
Carpenter, C. B.	11	11	..	..	Muniz B., L.	5	8	4	5
Constanten, T. C.	13	14	..	..	Murphy, A. T.	..	..	4	4
Covell, R. B.	2	2	..	..	Newton, C. S.	3	3	8	8
Cragg, T. A.	96	101	134	192	Nightingale, H. C.	4	10	5	8
de Kock, R. P.	140	756	138	539	Oberstatter, A.	..	..	7	15
Diedrich, Del.	2	3	..	..	Olmsted, M.	2	2	7	7
Diedrich, G.	2	3	..	..	Oravec, E. G.	148	209	170	387
Douglas, J.	..	..	3	4	Orchiston, D. W.	14	90	15	46
Drilling, J. S.	3	3	..	..	Pearcy, R. E.	1	1	2	2
Engelkemeir, D.	9	33	9	27	Pearlmutter, A. E.	18	32	..	..
Erpenstein, O. M.	11	31	11	22	Peltier, L. C.	24	102	31	139
Fallon, F. W.	1	1	2	2	Price, R. T.	..	..	19	19
Farmer, R.	..	..	5	5	Quester, W.	..	..	8	25
Fejes, J.	1	2	..	..	Renner, C. J.	..	..	147	184
Fernald, C. F.	260	650	206	439	Ricker, C. L.	4	4	..	..
Flavin, J.	1	8	..	..	Rizzo, P. V.	6	12	6	9
Ford, C. B.	32	32	52	53	Robinson, L. J.	39	56	3	42
Frogel, J. A.	3	3	3	3	Rosalsky, R.	1	1	..	..
Fuller, K.	81	83	19	23	Rosebrugh, D. W.	14	101	13	108
Gonthier, A.	12	39	16	25	Schiff, S.	6	6	21	21
Harries-Harris, E.	1	2	..	..	Sealy, R. N.	9	21	16	33
Hartmann, F.	145	173	142	163	Seldon, P.	14	14	..	..
Hicks, R. L.	..	..	4	17	Severin, M. A.	8	21	..	..
Hiett, L.	5	20	6	11	Sharpless, A. P.	6	6	20	20
Hudson, J. A.	2	2	4	4	Sheldon, L.	5	5	..	..
Humphrey, D. R.	10	11	..	..	Sherwood, D. A.	5	30	5	33
Hunter, T.	1	1	..	..	Shinkfield, R. C.	6	14	3	5
Hurless, C.	9	45	7	17	Skhal, R. G.	2	2	..	..
Hutchings, N. O.	..	..	11	17	Smith, G. W.	2	2	..	..

*plus 55m AE Aqr

Observers	Sept.		Oct.		Observers	Sept.		Oct.	
	Var.	Ests.	Var.	Ests.		Var.	Ests.	Var.	Ests.
Smith, J. R.	5	5	9	9	van Zyl, L. L.	48	140	48	125
Staer, R. R.	1	14	..	..	Venter, S. C.	25	57	..	..
Stanton, R.	43	46	14	16	Vodrazka, G.	6	8	5	29
Taboada, D.	36	41	28	28	Walsh, J.	5	7	..	..
Takeuchi, T.	3	4	..	..	Wells, K. A.	4	4	5	5
Tavares, O. C.	14	25	8	10	Williamson, L. J.	6	14	5	6
Thomas, M. A.	3	29	2	44	Williamson, P. L.	..	..	3	3
Topp, G.	4	6	..	..	Wilson, V. A.	4	4	18	20
Traynor, F.	4	5	..	..	Wyckoff, J.	18	29	..	..
Tsai, C. H.	..	..	36	64	Yamada, T.	36	103	20	20
Valdez, M.	3	3	14	14					

Reginald de Kock once again made the greatest number of observations during the year, 5,824. He was followed by Cyrus Fernald with 4,721; then came Rodrigo de la Vega of Chile with 4,096; Edward Oravec, 3,874; Thomas Cragg, 3,138; Robert Adams, 2,044; D. W. Orchiston, 2,024. Eight more observers made between 1,000 and 2,000 observations: Ferdinand Hartmann, Tatsuo Yamada, Curtis Anderson, G. B. Lacchini, Werner Braune, Charles Giffin, Leslie Peltier, and Leif Robinson. Thirty-one observers became "Inner Sanctum" members, with observations fainter than 13.8.

The dates of meetings during our 50th Anniversary Year (1961) have been set as follows: on May 26–28, we meet in Ottawa, at the kind invitation of the Ottawa Centre of the Royal Astronomical Society of Canada; and on October 12–15 we have our Annual Meeting at the Harvard College Observatory in Cambridge. We hope all our members and friends will help us celebrate and will plan to attend these meetings.

A.A.V.S.O. Nova Search Report (from George Diedrich, Chairman). Observations of nova search areas were made by the following 23 observers for a total of 649 area-nights reported. Each name is followed by the number of observations made in July and then August, 1960. Mrs. E. E. Bridgen—22, 23; I. P. Debono—16, 14; F. J. DeKinder—15, 23; D. Diedrich—8, 5; G. Diedrich—9, 7; Paul Evans—50, 0; K. Fuller—6, 20; G. Gaherty, Jr.—8, 10; D. Humphrey—32, 19; W. Isherwood, Jr.—19, 21; J. Low—0, 8; D. Matthies—3, 0; H. Nightingale—7, 6; D. W. Orchiston—27, 14; C. J. Phillips—0, 51; R. Price—0, 5; F. Traynor—8, 10; G. Vodrazka—5, 17; G. Wedge—12, 14; K. A. Wells—0, 24; K. Westbrook—0, 24; I. K. Williamson—19, 18; K. Zorgo—26, 24.

REVIEW OF PUBLICATIONS

Vistas in Astronomy, volume III edited by Arthur Beer. Pages 345; 7×9¾ in. New York, Pergamon Press Inc., 1960. Price $18.00.

This third volume of *Vistas* is a worthy successor to the earlier books which so admirably fulfilled the desire of many astronomers to honour the late Professor F. J. M. Stratton of Cambridge. That two more volumes are already in preparation is good news, for each article in this series is the work of an expert who brings the discussion of his particular topic to the present so that the "vista" of future developments may be made apparent.

The present volume contains eighteen articles. The contributors are mostly from the British Isles, but the U.S.S.R., the U.S.A., Sweden and Germany are also represented.

The articles in Part I range from the Design of Large Telescopes (Sisson), Techniques of Auroral Investigation (Jarrett), and Electronic Computers (Wrubel) to the recent comets Arend-Roland and Mrkos (Porter, Richter, Larsson-Leander, Woolf), Neptune (Lyttleton), Russian Satellites Observations (Beggs), Stellar Dynamics (Woolley), Light-Deflection in a Gravitational Field (Kluber), and the intriguing clock paradox problem (Cochran, Fock).

In the second section stress is laid on the need for more photoelectric multicolour data on the 70,000 stars brighter than visual magnitude 8.5 (Irwin) and in particular the infrared region and colour temperatures (Kron); photometry with the Cambridge Schmidt (Argue); a lengthy, critical survey of proposed theories of hot star emission lines (Pagel) and of star formation, indicating the important role of the galactic magnetic field (Mestel); Colour, Luminosity and Evolution of Stars (Eggen, who remarks that problems of stellar evolution and the cosmical distance scale are the *raisons d'être* of modern astronomy); the Visual Milky Way with his own drawings thereof (Gaposchkin); and finally Sciama's valuable essay on Cosmology favouring the steady state theory.

A. VIBERT DOUGLAS

The Earth, Its Origin, History and Physical Constitution (fourth edition) by Sir Harold Jeffreys. Pages 420; $9\frac{3}{4}\times6\frac{1}{2}$ in. New York, Cambridge University Press and Toronto, Macmillan Co. of Canada Ltd., 1959. Price 75*s*.

This is the fourth edition of a book that has been one of the classic references in geophysics since it was first published in 1924. It deals with those aspects of the subject in which the author is primarily interested and generally with those aspects to which he has made substantial scientific contributions. Thus, more than one-third of the book deals with seismology, and another large section deals with the earth's gravitational field, tidal friction and related matters. Smaller, but important, parts of the book deal with rheology, thermal history, and theories of origin and development.

Alterations to the fourth edition, though sometimes important, are not great. The main chapter headings remain unchanged, as do the figures and plates. Occasional sections have been revised considerably. The treatment of tidal friction is an example and the sections on the thermal history show some changes. Otherwise the revisions consist mostly of the insertion of new references with or without some additional discussion. References to Soviet conclusions on surface layering (added to page 82) and to satellite observations on the ellipticity of the earth (added to page 194) are examples of this type of change. Certain discussions of analytical techniques, such as of Lambert's extension of Stokes's integral method of gravity computation (page 144), have been augmented. The omission in the fourth edition of certain sections or sentences present in the third edition are sometimes as interesting as the new insertions.

If the strength of this book lies in the fact that it is restricted in scope to those topics in which the author is a distinguished authority, its weakness is its failure to represent adequately the spectrum of geophysical interests. Even in the field of seismology, the very extensive studies of crustal structure through surface waves made during the past ten years have been entirely ignored. Geomagnetism, particularly in relationship to the physics of the upper atmosphere, is relegated to a single page, despite the fact that more papers are probably being published now in this field than in any other geophysical topic. No attention is given to meteorology, oceanography, hydrology, geochemistry or applied geophysics. These omissions are not important in a reference book such as this, but they might provide an objection to its use as a text-book in most courses in geophysics. A more serious criticism applies to the sections on the age of the earth and on its thermal history which are noticeably

out of date in places. The revised value for Hubble's constant has been used on pages 282 and 283 but the older value persists on page 264.

Very few scientists studying the solid earth will not wish to own a copy of this book which is a very valuable reference. Whether the purchase of the fourth edition is worthwhile to one who already possesses a copy of the third edition is a more difficult question. It is the reviewer's personal view that this would hardly be justified by the relatively slight change in content.

R. D. RUSSELL

NOTES FROM OBSERVATORIES

DAVID DUNLAP OBSERVATORY, UNIVERSITY OF TORONTO, RICHMOND HILL, ONTARIO.

The Director and his colleagues are sincerely appreciative of the promise of substantial financial support which will eventually come to the Observatory as a result of the terms of the will of the late Mr. Walter J. Helm, as announced on page 297 of the December 1960 JOURNAL.

A great improvement in the reflectance of the 74-inch telescope has been effected by the removal from the Cassegrainian secondary mirror of the "permanent" base coat of chromium, applied in 1934 in the belief that it would improve the adherence of the original and subsequent aluminum coats.

The major optical components of the new all-reflection spectrograph are on order. Mr. Sidney Girling, retired instrument maker of the Dominion Astrophysical Observatory, spent two months at the Observatory making detailed design drawings for the case and optical plate of the spectrograph, and these parts too are now on order.

Gifts are gratefully acknowledged of an 8-inch optical flat, a three-inch achromat and an electric desk computer from Dr. R. K. Young, Director Emeritus. A new bench lathe has been purchased from the Jessie Dunlap Fund.

The laboratory model of a parametric amplifier, being designed and built by the radio astronomy group here, is performing well. This development is being conducted under contract from the Dominion Observatory, and when the final version is built it will be installed at the Dominion Radio Astrophysical Observatory at Penticton.

Mr. David Hogg, a Ph.D. candidate, spent several months during the autumn at the U.S. National Radio Observatory at Green Bank where he obtained observations of an H II radio source in Cassiopeia, using the 85-foot radio telescope.

Dr. K. O. Wright of the Dominion Astrophysical Observatory is spending the session here as Visiting Lecturer. Among recent visitors to the Observatory have been Dr. John A. O'Keefe of the Goddard Space Flight Centre and Dr. R. M. Petrie, Dominion Astrophysicist.

JOHN F. HEARD

THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

NATIONAL OFFICERS AND COUNCIL FOR 1960

Honorary President—The Hon. W. J. DUNLOP, D.PAED., Minister without portfolio.
President—PETER M. MILLMAN, PH.D., F.R.S.C., Ottawa
Vice-President—RUTH J. NORTHCOTT, M.A., Toronto
National Secretary—J. E. KENNEDY, M.SC., 252 College Street, Toronto 2B
National Treasurer—WILLIAM R. HOSSACK, PH.D., 252 College Street, Toronto 2B
Recorder—FREDERIC L. TROYER, Toronto
Librarian—W. T. TUTTE, PH.D., F.R.S.C., Toronto
Council—

Elective Members: ANNE B. UNDERHILL, PH.D., Victoria; DAVID A. KEYS, PH.D., F.R.S.C., Deep River; FRANK J. DEKINDER, Montreal

Past Presidents: HELEN S. HOGG, PH.D., F.R.S.C., Toronto; R. M. PETRIE, PH.D., F.R.S.C., Victoria

Representatives from Centres:

Calgary Centre: E. J. MCCULLOUGH, T. W. LAVIOLETTE (President)
Edmonton Centre: EARL MILTON, B.A., J. HARRINGTON (President)
Halifax Centre: REV. M. W. BURKE-GAFFNEY, S.J., B. W. ALLEN (President)
Hamilton Centre: G. M. VANSICKLE, S. J. BUNTAIN (President)
London Centre: W. GORDON GRAHAM, R. W. RICHARDSON (President)
Montreal Centre: C. M. GOOD, A. R. MACLENNAN (President)
Centre Français de Montréal: FLEURANGE LAFOREST, PIERRE LEMIEUX (President)
Ottawa Centre: W. L. ORR, M.D., IAN HALLIDAY, PH.D. (President)
Quebec Centre: MAURICE DROLET, J. ALFRED DUMONT (President)
Toronto Centre: JOHN F. HEARD, PH.D., F.R.S.C., LEONARD SEARLE, PH.D. (President)
Vancouver Centre: J. A. JACOBS, PH.D., F.R.S.C., V. J. OKULITCH, PH.D., F.R.S.C. (President)
Victoria Centre: NORMAN G. ROGERS, J. A. L. MUIR (President)
Windsor Centre: WILLIAM G. MITCHELL, LAMBERT HUNEAULT (President)
Winnipeg Centre: R. J. LOCKHART, B.A., J. SCATLIFF, M.D. (President)

Vol. 55, No. 1 FEBRUARY 1961 Whole No. 448

Sir William Herschel and His Place in the History of Science... *Walter Balderston* 1
Professor F. J. M. Stratton, F.R.S. ..... *R. O. Redman* 9
The Bright-Line Stars of Class B (*to be concluded*) ..... *Dean B. McLaughlin* 13
Tidal-Electric Power Generation (*to be concluded*) ..... *F. Keith Dalton* 23

CANADIAN SCIENTISTS REPORT—XXIV
The Stellar Population of the Galactic Nucleus ..... *Sidney van den Bergh* 34

VARIABLE STAR NOTES ..... *Margaret W. Mayall* 41

REVIEW OF PUBLICATIONS
Vistas in Astronomy, volume III edited by Arthur Beer; *The Earth, Its Origin, History and Physical Constitution* (fourth edition) by Sir Harold Jeffreys... 45

NOTES FROM OBSERVATORIES ..... *John F. Heard* 48

EDITOR—Ruth J. Northcott ASSISTANT EDITOR—Leonard Searle

ASSOCIATE EDITORS—C. S. Beals, R. M. Petrie, A. Thomson

COMMUNICATIONS TO THE EDITORS SHOULD BE ADDRESSED TO
David Dunlap Observatory, Richmond Hill, Ontario

The Society publishes this JOURNAL bi-monthly (February, April, June, August, October and December) and the OBSERVER'S HANDBOOK annually. Single copies of the JOURNAL are 75 cents, of the OBSERVER'S HANDBOOK, one dollar.

Membership, which includes the publications, is open to anyone interested in astronomy. Annual dues are $5.00; life membership is $75.00. Applications for membership or publications should be made to THE ROYAL ASTRONOMICAL SOCIETY OF CANADA, 252 COLLEGE STREET, TORONTO 2B, ONTARIO.